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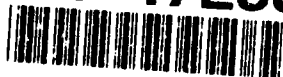
THYSSEN-WAAS ICE TRANSIT BOW SEAKEEPING STUDY

by
William L. Thomas III
Wah T. Lee

RC/SHD-1338-03 Thyssen-Waas Ice Transit Bow Seakeeping Study



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With satisfactory results from the Mudyug, a seakeeping study was performed of Thyssen-Waas forebodies married to LSD-41 and FFG-7. Numerical predictions indicate the hull forms having a Thyssen-Waas forebody will have less pitch and heave but will slam more frequently in the forward stations than convention naval vessels in higher Sea States. The increase in slamming frequency can be attributed to the flat forebody and shallow stem angle of the Thyssen-Waas bow.

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CONTENTS

	Page
NOMENCLATURE	v
ABSTRACT	1
ADMINISTRATIVE INFORMATION	1
BACKGROUND	1
INTRODUCTION	2
OPEN WATER SEAKEEPING INVESTIGATIONS	3
Objective	3
Approach	3
THYSSEN-WAAS MUDYUG MOTION COMPARISONS	4
HSVA Model Test	4
MUDYUG Comparison Study	5
Results	6
Discussion	7
THYSSEN-WAAS MUDYUG SEAKEEPING STUDY	7
Results	7
THYSSEN-WAAS LSD-41 SEAKEEPING STUDY	8
Results	8
THYSSEN-WAAS FFG7 SEAKEEPING STUDY	9
Results	9
CONCLUSIONS	10
RECOMMENDATIONS	11
REFERENCES	29
APPENDIX A: MUDYUG	A-1
APPENDIX B: LSD41	B-1
APPENDIX C: FFG7	C-1

FIGURES

1. Icebreaker Mudyug Body Plan with Thyssen/Waas forebody.	13
2. JONSWAP and Bretschneider spectra; $H_{1/3} = 4$ meters.	14
3. LSD-41 Body Plan.	15
4. LSD-41 Body Plan with TNWS forebody.	16
5. LSD-41 Body Plan with modified TNWS forebody for resistance considerations.	17
6. FFG-7 Body Plan.	18

FIGURES (Continued)

	Page
7. FFG-7 Body Plan with modified TNWS forebody for resistance considerations.	19

TABLES

1. HSVA TNWS "Mudyug" model test results.	20
2. Comparison between HSVA "Thyssen/Waas Mudyug" model and SMP84 hydrostatics.	21
3. Vertical displacement comparison between HSVA model test and SMP84 numerical predictions.	22
4. Pitch motion comparison between HSVA model test and SMP84 numerical predictions.	23
5. Comparison between original LDS41 and two proposed ice breaking versions having TNWS type forebodies.	24
6. LSD limiting speeds (20 SLAMS/HR).	25
7. Comparison between Original FFG-7 and Proposed Icebreaking Version having a Thyssen-Waas Forebody.	26
8. FFG Limiting Speeds (20 SLAMS/HR).	27

NOMENCLATURE

A_{WP}	Waterplane area
B	Beam
C_B	Block coefficient
CG	Center of Gravity
C_M	Midship section coefficient
C_P	Prismatic coefficient
C_{PF}	Prismatic coefficient forward of midships
C_{WPF}	Waterplane area coefficient forward of midships
FP	Forward Perpendicular
g	Acceleration of gravity
$H_{1/3}$	Significant Wave Height
KM	Height of metacenter above baseline
L_{WL}	Length at the waterline
L_{PP}	Length Between Perpendiculars
T	Draft at midships, (station 10)
T_ϕ	Natural roll period
Z_D	Deckhouse vertical displacement
\ddot{Z}_D	Deckhouse vertical acceleration
Δ	Displacement
α	Relative ship-wave heading angle

ABSTRACT

Conventional naval hull forms allow limited capability in ice covered waters. The potential of the Thyssen-Waas hull form to increase ice breaking effectiveness with a reduction in ice breaking resistance raises possibilities for improving the performance of selected U. S. Navy ships in arctic regions. It is therefore desirable to investigate the performance of a Thyssen-Waas ice transit bow married to selected naval ships.

This objective was accomplished in three steps. First, a modification was made to the Navy's Ship Motion Program (SMP) to accurately model the Thyssen-Waas forebody. This was necessary to properly represent the bulges of the reamers/cutters in the bow sections. Second, an estimation regarding the quality of the motion predictions was made by comparing the SMP motion predictions with model test data for the Thyssen-Waas icebreaker Mudyug.

With satisfactory results from the Mudyug comparison, a seakeeping study was performed of Thyssen-Waas forebodies married to LSD-41 and FFG-7. Numerical predictions indicate that hull forms having a Thyssen-Waas forebody will have less pitch and heave but will slam more frequently in the forward stations than convention naval vessels in the higher Sea States. The increase in slamming frequency can be attributed to the flat forebody and shallow stem angle of the Thyssen-Waas bow.

ADMINISTRATIVE INFORMATION

This report is submitted in partial fulfillment of Milestone 4, Task 1 of the Enabling Technologies (RH21E45) of the Surface Ship Technology Block Program (ND1A/PE0602121N). The work described herein was sponsored by the Chief of Naval Research, Office of Naval Technology, Code ONT211 and was performed by Code 1561 of the David Taylor Research Center during FY91 under work unit number 1-1239-110.

BACKGROUND

The Thyssen-Waas hull form promises to be a significant advance in ice breaking technology. Conventional icebreakers cause ice failure by a combination of ramming and crushing the ice as the bow climbs over the ice sheet. The primary ice failure mode involves a combination of crushing and bending. Once the ice is broken in this manner, conventional ice breaking hull forms displace broken pieces of ice by either forcing them

below the waterline in a path toward the propeller in-flow field or along the side of the ship, causing large frictional losses which increase ship resistance^{1, 2}.

The Thyssen-Waas hull form is of special interest in contrast to conventional icebreakers because it takes advantage of a more efficient ice breaking technique. Ice runners along the perimeter of the forebody induce ice failure as a shear crack forward of the vessel. The forward progress of the ship creates cantilever loads to the ice leading to failure by bending across the front of the bow³. The broken ice slab moves down and under the forward portion of the hull and is split in half by the increasing vee of the stem line. Flow field characteristics of the hull coupled with buoyant properties of the ice cause each respective half of the broken ice slab to move outboard away from the hull and under the ice sheet. This produces a cleanly cut ice channel with less propulsive power in comparison with conventional icebreakers¹.

INTRODUCTION

Recent model tests at the David Taylor Research Center (DTRC) indicate that conventional naval combatant hull forms allow very limited or no penetration capability in ice covered waters^{4, 5}. The U. S. Navy presently has no ice capable surface ships. The majority of U. S. Icebreakers belong to the Coast Guard. Although Coast Guard ice breakers are very capable, they are configured more for maritime and research duties than for combat operations.

In recent experiments conducted by the Soviet Union, a conventional icebreaker named *Mudyug* was converted to a Thyssen-Waas hull form by replacing the original bow with a prefabricated Thyssen-Waas forebody. Test results were encouraging enough to convince the Soviets to install the Thyssen-Waas forebody on a larger polar icebreaker¹.

The potential of the Thyssen-Waas forebody to increase ice breaking effectiveness with a reduction in ice breaking resistance raises possibilities for improving the performance and capabilities of U. S. Navy ships used in arctic operations. While it may be impractical to consider modifying an entire fleet of ships for ice breaking operations, significant gains in ice penetration capabilities might be gained by the presence of several Thyssen-Waas modified ships. In support of this idea, it is desirable to conduct

preliminary investigations of the performance capabilities of a Thyssen-Waas ice transit bow married to a naval vessel.

OPEN WATER SEAKEEPING INVESTIGATIONS

Objective

Feasibility studies of new hull forms require, among other things, a study to assess the potential impacts of hull form design changes on seakeeping qualities. First order predictions can be performed using existing numerical prediction models. However, it must be understood, that numerical prediction models work best with hull forms with characteristics similar to those for which the numerical model was derived.

The objective of this study is to provide numerical predictions of the seakeeping performance of two naval vessels fitted with Thyssen-Waas forebodies and provide recommendations in terms of performance for future studies.

Approach

Typical Navy seakeeping investigations utilize the U. S. Navy's Ship Motion Program, SMP84^{6, 7} to estimate 6 degree of freedom motion characteristics of conventional hull forms in specified seas at selected speeds. Most validation of SMP84 has compared the numerical predictions with model tests performed on conventional surface combatants and auxiliary hull forms.

The need for a Thyssen-Waas seakeeping study was indicated by the radical forebody shape which exists in contrast with conventional surface combatants. The principal features of the Thyssen-Waas forebody include a transversely flat waterline at the bow, a maximum waterline beam located at the forward perpendicular, low stem angle, and high flare angles below the waterline. (The underwater body is displayed in Figure 1). The combination of a flat bottom, low stem angle, and shallow draft in the stem area indicated that this hull form might have a predisposition for slamming in open water at the higher sea states.

The seakeeping evaluation on a hull form representing a Thyssen-Waas bow married to naval vessels was conducted in three steps. First, SMP84 was modified to accurately

model the Thyssen-Waas forebody. The modified version of SMP84 allowed up to 20 offset points per station in order to accurately represent the bulges of the reamers/cutters on the Thyssen-Waas bow sections. An evaluation of the quality of the modified SMP84 motion predictions was made during the second stage of this investigation when SMP84 predictions were made for the icebreaker *Mudyug* and compared a model test performed at the Hamburg Ship Model Basin, HSVA⁸.

With satisfactory results from the *Mudyug* comparison, the third and final step of performing a seakeeping study of Thyssen-Waas forebodies married to two naval vessels was performed.

THYSSEN-WAAS MUDYUG MOTION COMPARISONS

To estimate the quality of SMP84 ship motion predictions for a Thyssen-Waas hull form, a comparison was made with model test results supplied by the Hamburg Ship Model Basin (HSVA)⁸. Offsets and a body plan of ship model 3268-0101 representing the Thyssen-Waas *Mudyug* were supplied by HSVA. Appendage information relevant to SMP84 were obtained from Germanifcher Lloyd⁹.

HSVA Model Test

HSVA conducted free running model tests in representative seas having relative headings of $\alpha = 180$ (head seas) and $\alpha = 150$. JONSWAP- type longcrested irregular seaways were used representative of Beaufort Force 6, 8, and 10. Pitch, roll and vertical accelerations were measured at the FP (\ddot{Z}_F) and at the Deckhouse (\ddot{Z}_D). Results, as published by HSVA⁸ are presented in Table 1.

Several comments regarding the HSVA report are appropriate. First, the near head seas condition ($\alpha = 150$) model test results were eliminated from this comparison study due to model test procedure. The results were obtained by steering the model on zig-zag courses due to the restricted width of the tank⁸. It is the opinion of the authors that this procedure was not sufficiently rigorous for a SMP84 comparison. Ship motions and speed degradations associated with the zig-zags will probably influence the results.

The values presented for the vertical accelerations at the Deck house, (\ddot{Z}_D) and FP (\ddot{Z}_F) were also determined to be unsuitable for SMP84 comparison. A close examination

of Table 1 indicates that both significant and maximum values were calculated for positive and negative peak accelerations. This differs from calculating the significant value of the time histories. Due to the absence of the time histories, there exists no simple method to convert these values into a form for SMP84 comparison. It is also disturbing to note that some of the maximum values for the peak accelerations are high in value. Peak accelerations as high as .8 g's indicate the possibility of a saturated, "ringing" accelerometer or *very* high accelerations.

The discussion at this point leave motion candidates for comparison to be Pitch, Roll, and Deckhouse vertical displacement, (Z_D). In theory, for longcrested seaways, roll values in head seas, ($\alpha = 180$) are zero. However, during a model test, it is often very difficult to obtain and maintain this precise heading. The roll values in Table 1 were thus eliminated from this comparison study.

Deckhouse vertical displacement, (Z_D) deserves some discussion. This value was obtained by double integration of the filtered \ddot{Z}_D . Although the authors have doubts about the unfiltered \ddot{Z}_D signals it was decided that the filtered Z_D could be used. Thus, pitch and Z_D were the motions deemed suitable for the comparison study.

MUDYUG Comparison Study

Ship motion predictions using the modified version of SMP84 were made for pitch and Z_D at significant wave heights comparable to the model test. It must be noted that the model test used "JONSWAP-type" seaways⁸ while SMP84 uses the Bretschneider wave spectra⁶. The comparison of JONSWAP- type seaways to Bretschneider seaways deserves some discussion.

A JONSWAP spectrum can be thought of as a distortion of a Bretschneider spectrum in terms of characteristic wave height and modal period¹⁰. As shown in Figure 2, the JONSWAP has a higher peak with a corresponding reduction in spectral ordinate on either side of the peak. The JONSWAP is more narrow banded than the corresponding Bretschneider. Of course, in comparison to the JONSWAP, the Bretschneider has a smaller peak, but spreads its energy over a broader band of wave frequencies. Since pitch and heave motions are heavily damped, with resonant peaks which are not very pronounced, it is the opinion of the authors that in head seas conditions, little dif-

ference will be seen between the JONSWAP model test results and the Bretschneider SMP84 motion predictions for broad banded responses. (This assumption would not be acceptable for the lightly damped, narrow band responses such as roll.) The present state of SMP84 indicates that satisfactory comparisons are made if JONSWAP model test data falls within 20% of the SMP84 predictions.

Ship motion predictions for the Thyssen-Waas *Mudyug* were performed using a modified version of SMP84 which allowed the use of up to 20 offsets per station. More than 10 offset points were needed in order to accurately represent the bulges of the reamers/cutters on the Thyssen-Waas forebody. (See Figure 1). When roll dampening becomes a major concern, one more consideration is in order when using SMP84 with Thyssen-Waas hullforms. The centerline ice cutter on the forebody can be visualized as a "backwards skeg." Although SMP84 allows the use of multiple skegs, it will not allow the user to describe a skeg which tapers toward the stern⁶. This problem was overcome by modeling an equivalent skeg having the same area and same centers of pressure as the "backwards skeg." The final SMP84 description of the Thyssen-Waas *Mudyug* appears to be reasonable and satisfactory. A comparison between HSVA model test and SMP84 hydrostatics for the *Mudyug* are presented in Table 2.

Results

Vertical Displacement and Pitch comparisons between the HSVA model test and SMP84 predictions are displayed in Tables 3 and 4. Numerical predictions by SMP84 yielded values for Z_D that fell easily within 20% of the model test data with the exception of one case (at the lowest seaway) where the SMP84 prediction was 38% above HSVA. There is no immediate explanation for the 38% discrepancy in this particular sea condition. It may be related to the filtering of the acceleration data, \ddot{Z}_D . It is particularly interesting to note in Table 1 that in the lowest sea condition, in head seas, a high maximum positive peak \ddot{Z}_D value was found (3.45 m/s^2) with a corresponding calculated value Z_D of 1.01 meters. Yet in the second seaway condition, in head seas, a lower maximum positive peak \ddot{Z}_D (3.23 m/s^2) was associated with a higher Z_D of 2.48 meters. It is impossible to reach definitive conclusions regarding this discrepancy without the time history data. It is the suspicion of the authors that the model test

value for Z_D should have been higher than 1.01 meters in this instance. This belief favors the predicted value of 1.48 meters.

The pitch predictions produced by SMP84 fell easily within 23% of the HSVA model test values. (See Table 4.) This is very acceptable.

Discussion

Fairly good agreement has been observed between the model test and numerical predictions of *Mudyug* head seas vertical acceleration and pitch. This indicates that numerical prediction techniques might provide appropriate first order predictions for other Thyssen-Waas hulls forms in head seas conditions. This numerical prediction technique for vertical motions will now be applied to naval vessels married to Thyssen-Waas bows.

THYSSEN-WAAS MUDYUG SEAKEEPING STUDY

Seakeeping predictions performed throughout the rest of this study will include SMP84 calculations in head seas conditions for pitch, heave, and slamming. Slamming predictions were performed by SMP84 utilizing methods cited by Ochi and Motter¹¹. Motion predictions were performed in longcrested seaways representing Sea States 4 ($H_{1/3}=6.2$ feet-1.88 meters), 5 ($H_{1/3}=10.7$ feet-3.25 meters), and 6 ($H_{1/3}=16.4$ feet-5.0 meters). To maintain consistency in documentation, a seakeeping study was performed on the Thyssen-Waas *Mudyug* hull form.

Results

Pitch, heave, and slamming motion predictions are presented in APPENDIX A. Of particular interest is slamming response. The shallow stem angle and the wide, flat bottom of the Thyssen-Waas forebody indicate that large forces due to slamming can occur forward of Station 3. This is significant, since typical slamming studies involved with conventional hull forms choose the the underside of the hull at station 3 as the location where the body is flat enough to cause large slamming forces. Since flatness in the Thyssen-Waas forebodies seemed to occur farther forward in the forebody, a more representative location was chosen for the slamming calculations. The results predict a

significant number of slams at Station 0 at speeds greater than 6 knots in Sea State 6. These predictions for *Mudyug* indicate that slamming might become a problem in the marriage studies involving the naval combatants.

THYSSEN-WAAS LSD-41 SEAKEEPING STUDY

The first naval hull form for the marriage study was LSD-41. (See Figure 3). This vessel was of interest due to its amphibious warfare capabilities. The evaluation process involved with modeling a Thyssen-Waas bow on this class of ship yielded two possible configurations. In the first case, a hull form which closely resembled the Thyssen-Waas *Mudyug* bow was fitted to the bow of the ship in the numerical model. The forebody contained the same shallow stem angle observed on the Thyssen-Waas *Mudyug* and was fitted forward of station 5.5. (See Figure 4). For the purposes of this report, this hull configuration will be referred to as *LSDWAAS*.

Preliminary estimates, using numerical modeling techniques indicated that *LSD-WAAS* had undesirable resistance characteristics. For this reason, a second bow was fitted to LSD-41 in the numerical model. (See Figure 5). This configuration will be described in this report as *NEWLSD41*. The new forebody represents an altered version of the Thyssen-Waas forebody to reduce C_{PF} for powering considerations.

Ship motion predictions for the original and two modified LSD hull forms were made using the modified version of SMP84 which permits the use of up to 20 offsets per station. The centerline ice cutters on the modified forebodies were modeled as equivalent skag having the same area and centers of pressure as the "backwards skag" in accordance with SMP84 modeling techniques. Pitch, heave, and slamming predictions were performed for each hull form configuration.

Results

The general characteristics of the original LSD-41 hull form and the modified versions are listed in Table 5. Longcrested head seas ship motion predictions for pitch, heave, and slamming are presented in APPENDIX B.

Both modified Thyssen-Waas (TNWS) forebodies for LSD-41 are predicted to have higher values for KM, which might cause the vessel to become more stiff in terms of

roll. The flat, bulky TNWS forebodies displayed slightly lower SMP84 pitch and heave motion predictions in the higher sea states in comparison with the original LSD-41 hullform. As illustrated in the slamming figures, both TNWS forebodies are predicted to experience performance degradations in comparison with the original LSD-41 due to increased slamming in higher sea states. The projected increase in slamming can directly be attributed to a shallow draft at the bow combined with the relatively flat, wide bottom and shallow stem angle of the TNWS forebodies. Limiting speed predictions for LSD-41 and *NEWLSD41* in longcrested, head seas are listed in Table 6. The listed speed limits are based on SMP84 slamming predictions with a threshold defining unacceptable slamming at the rate of 20 slams per hour.

THYSSEN-WAAS FFG7 SEAKEEPING STUDY

The second naval hull form for the marriage study was FFG-7. This vessel was of interest because it represents a typical conventional small naval combatant. The modified forebody configuration called *FFG7WAAS* was provided by HSVA. A review of the underwater hull form in Figures 6 and 7 indicates little change in the underwater body between the conventional and ice breaking configurations. The most obvious difference between the two hull forms is that the *FFG7WAAS* has a shallower stem and is slightly flatter in the forebody near the FP. The outboard ice cutting keels on *FFG7WAAS* are above the waterline. A comparison between FFG-7 and *FFG7WAAS* hydrostatics is presented in Table 7.

Results

Heave, pitch and slamming comparisons for longcrested seas between FFG-7 and *FFG7WAAS* are displayed in APPENDIX C. Pitch and heave responses are predicted to be very similar for both hull forms due to similarities in the underwater hull configurations. Slamming frequency is predicted to be worse in the *FFG7WAAS* configuration due to the shallower stem angle and an increase in flatness of the underwater body near the FP. Limiting speed predictions for FFG-7 and *FFG7WAAS* in longcrested, head seas are listed in Table 8. The listed speed limits are based on SMP84 slamming predictions with a threshold defining unacceptable slamming at the rate of 20 slams per

hour.

CONCLUSIONS

First order numerical predictions of seakeeping performance of a Thyssen-Waas hullform can be successfully made using a modified version of SMP84 in head seas, longcrested seaways. The modified version of SMP84, which allows 20 offsets per station to describe the complex Thyssen-Waas forebody, provides credible predictions for pitch, heave, and slamming. The SMP84 output appears consistent and follows expected trends, including the prediction of slamming on the Thyssen-Waas forebody which is relatively flat, broad in the forebody, and shallow in stem angle as compared to conventional hull forms. The HSVA model test accomplished its original purpose of comparing head seas performance of *Mudyug* before and after the installation of the Thyssen-Waas forebody, but was lacking in detail and consistency in results to allow more than a limited comparison with SMP84 predictions.

A close review of the HSVA *Mudyug* seakeeping model test report⁸ indicates that a great deal of attention must be paid to HSVA's conclusion. The HSVA report compared the original *Mudyug* hull form with the modified version having the TNWS forebody. HSVA concluded that "the vertical motions and pitch motions of the ship with the TNWS forebody were smaller due to the larger and fuller waterline area"⁸. This statement appears to be valid. However, one should not draw from this statement a conclusion that Thyssen-Waas vessels are great seakeepers. It is the authors suspicion that the original *Mudyug* was probably a poor seakeeper. Seakeeping improvements made to the *Mudyug* by the installation of the TNWS forebody represent minor improvements to a poor seakeeper.

The Thyssen-Waas forebody shows promise in terms of advances in ice breaking technology. Milano¹ indicates that this type of vessel is also very promising in terms of seakeeping performance. Preliminary estimates indicate that hull forms having this type of forebody will slam more frequently in forward stations than conventional open water naval vessels. The increase in slamming frequency can directly be attributed to the flat forebody and shallow stem angle of the TNWS bow.

The most promising Thyssen-Waas hull form, the *FFG7WAAS* represents an TNWS type configuration which was especially adapted for an FFG-7 by HSVA. The authors of this report were very encouraged by the implication that TNWS-type forebodies can be installed on naval combatants with little change in the underwater body. This procedure of "tailoring" the forebody to the individual vessel appears to allow the creation of ice breaking hull forms having little change in pitch and heave response, in comparison with the original body.

RECOMMENDATIONS

It is recommended that further research efforts concerning this topic be directed toward a "tailored" TNWS forebody married to naval combatant. Additional seakeeping investigations are recommended to explore additional ship motion responses, including roll. Furthermore, a structural investigation is recommended to predict and quantify slamming pressures to determine whether or not an increase in slamming frequency is a serious issue for the ice breaker bow. On the one hand, the ice breaking bow may have the capability withstand more slamming forces without damage. On the other hand, the slamming forces may be significant and cause a reduction in open water performance because the ship will need to reduce speed in slamming situations. A partial degradation in open water slamming performance may be a reasonable trade-off in order to provide a new ice breaking capability. A model test is strongly advised to confirm these predictions.

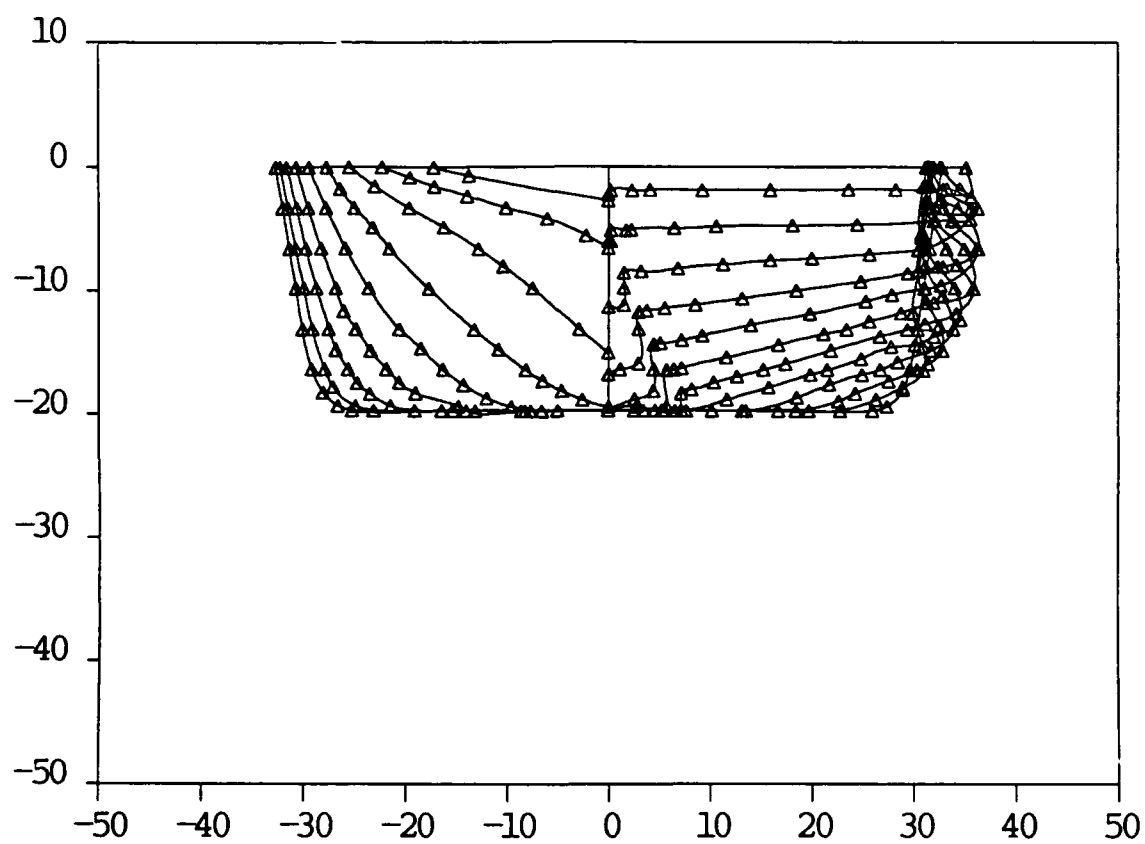


Fig. 1. Icebreaker Mudyug Body Plan with Thyssen/Waas forebody.

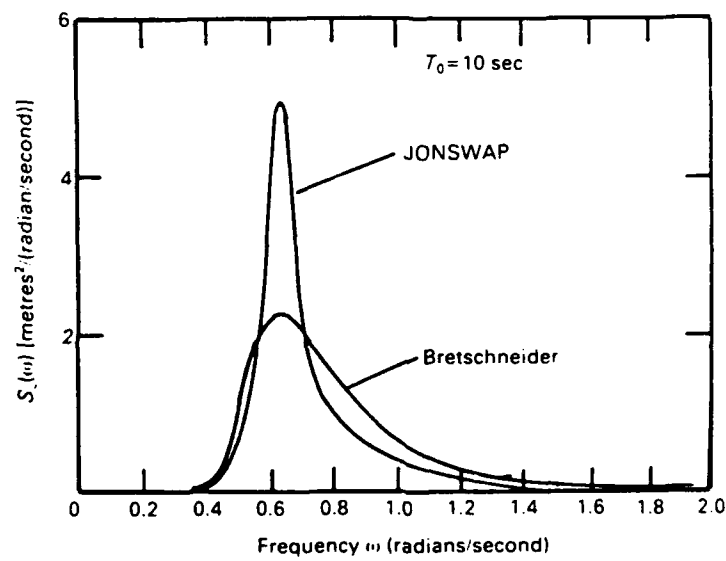


Fig. 2. JONSWAP and Bretschneider spectra; $H_{1/3} = 4$ meters. (From Reference 10.)

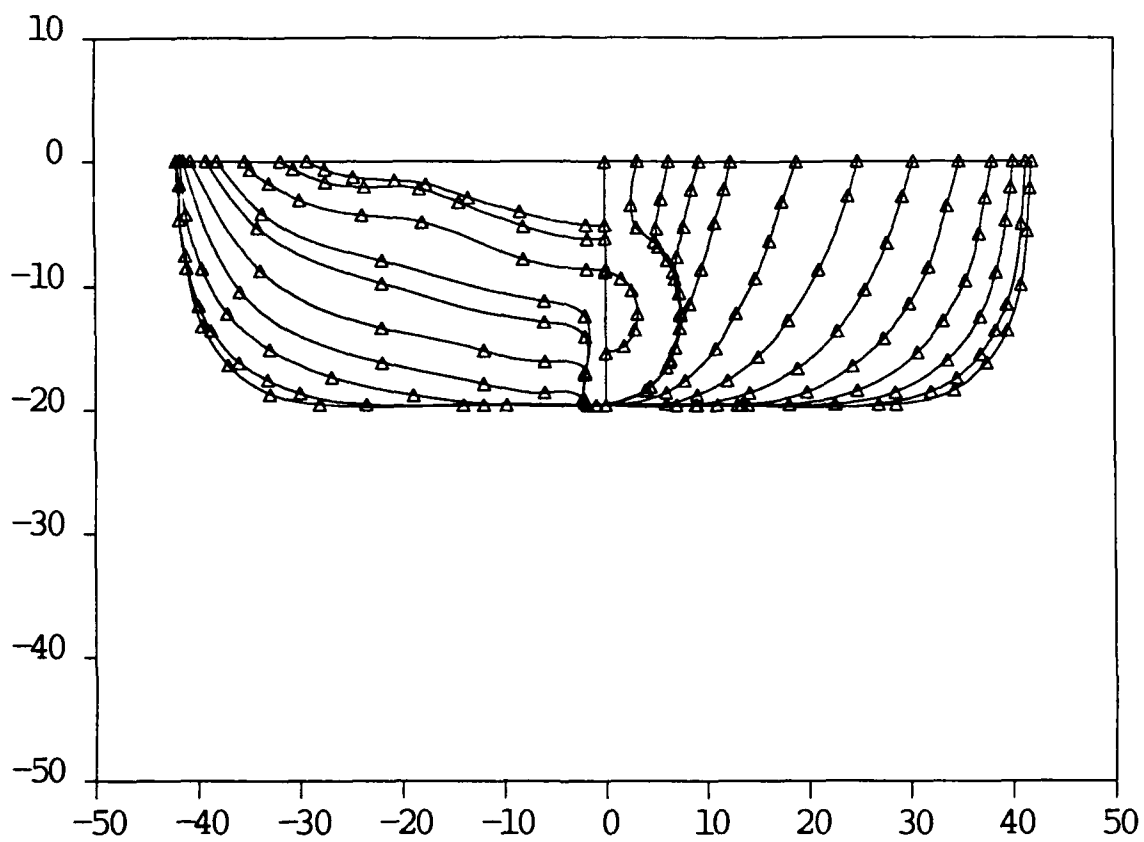


Fig. 3. LSD41 Body Plan.

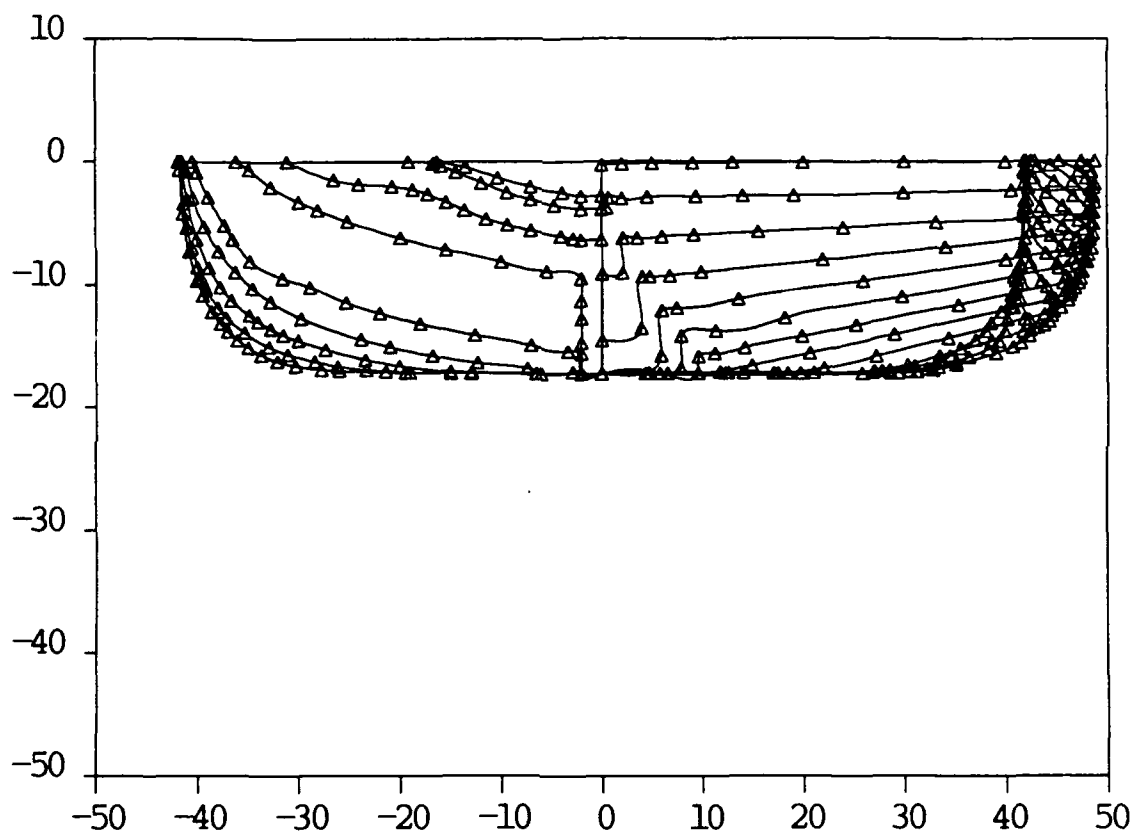


Fig. 4. LSD41 Body Plan with Thyssen/Waas forebody (LSDWAAS configuration).

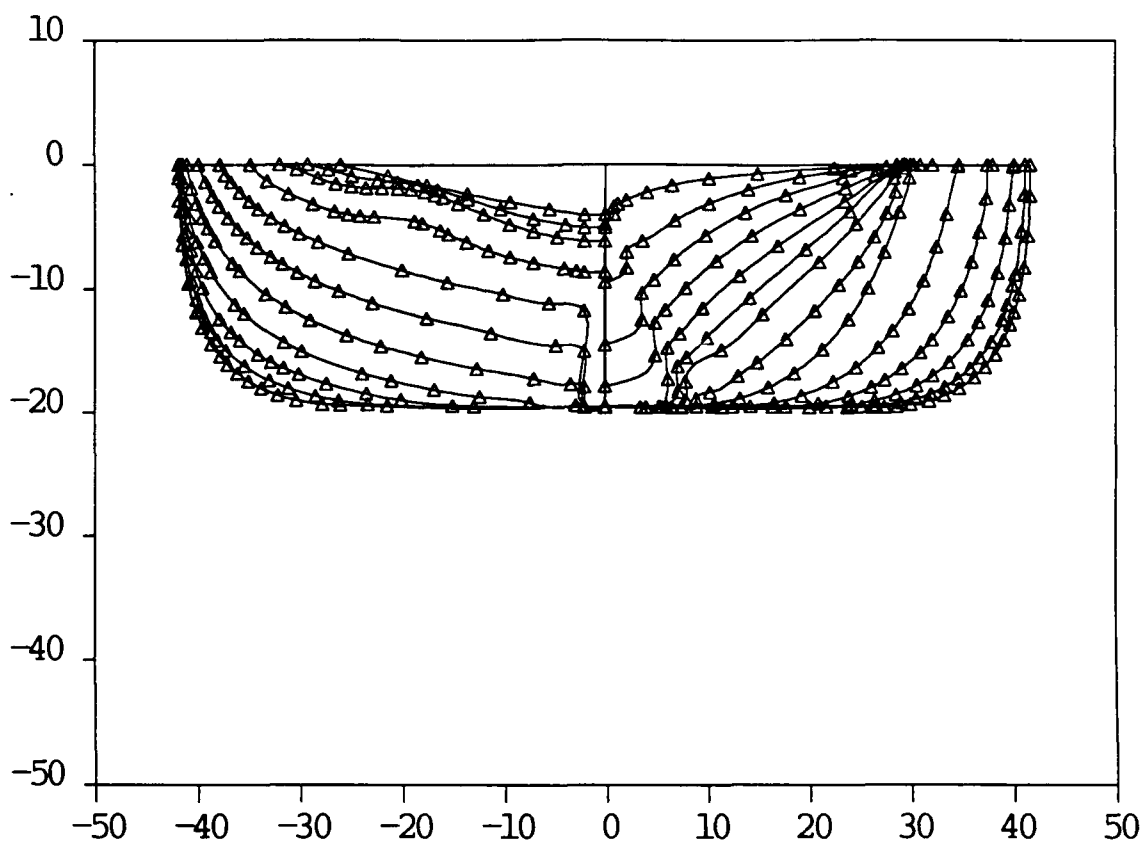


Fig. 5. LSD41 Body Plan with Thyssen/Waas forebody modified for resistance considerations (NEWLSD41 winged configuration).

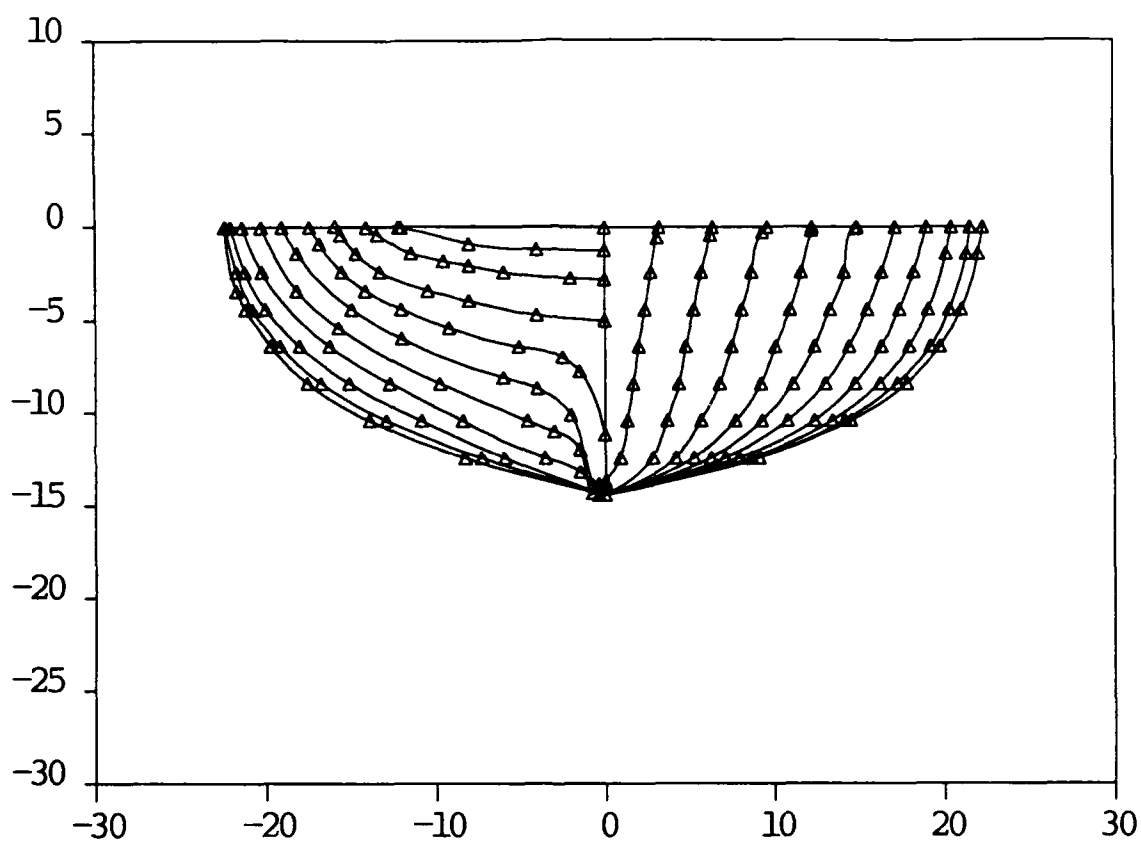


Fig. 6. FFG7 Body Plan.

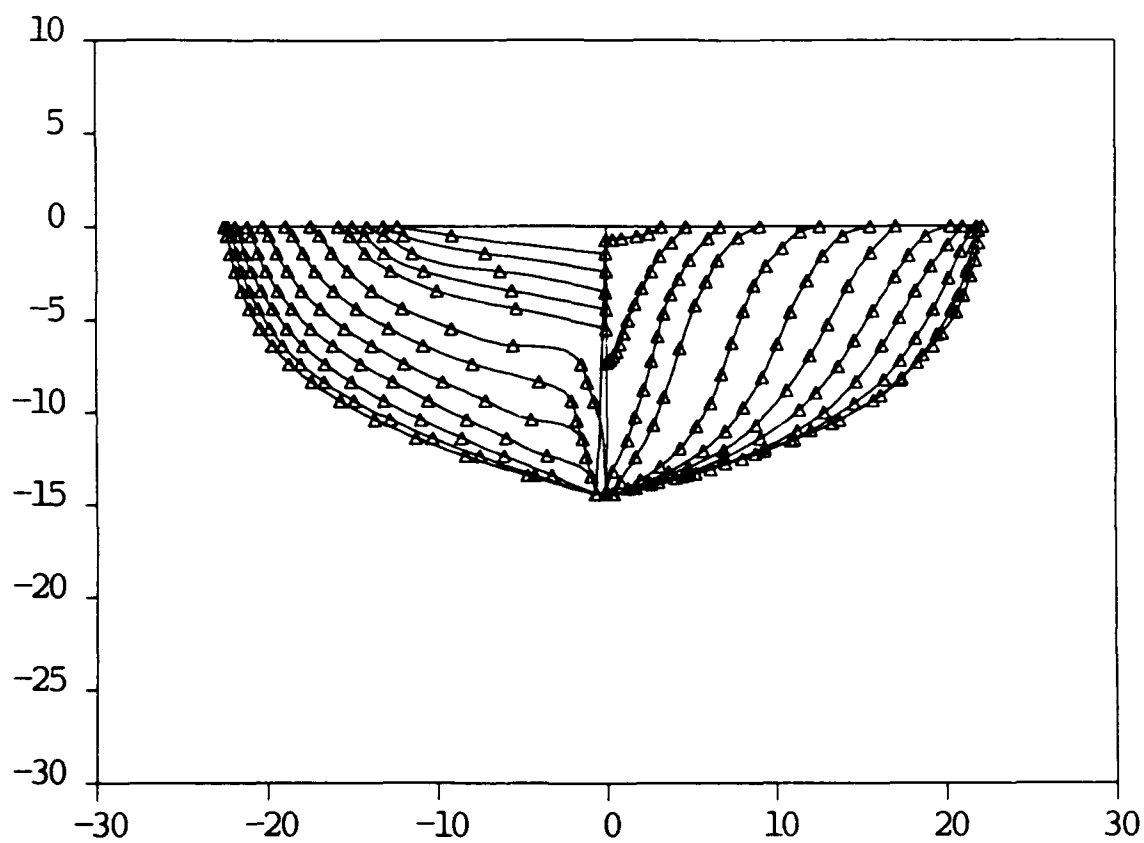


Fig. 7. FFG7 Body Plan with Thyssen/Waas forebody modified for resistance considerations (FFG7WAAS).

seaway	course (°)	V_C (kn)	V_S (kn)	Z_D (m)		θ (°)		ϕ (°)		\ddot{Z}_F (m/s ²)				\ddot{Z}_D (m/s ²)			
				sign.	max.	sign.	max.	sign.	max.	+	sign.	-	max.	+	sign.	-	max.
I	180	16	13.9	1.01	1.78	2.2	4.3	0.4	1.3	2.90	2.00	7.48	3.22	1.41	1.24	3.45	2.23
	150	16	-	1.13	1.98	2.4	4.1	1.1	1.7	2.31	1.97	4.97	3.18	1.12	1.26	2.39	2.08
II	180	14	9.8	2.48	3.71	5.4	8.0	0.7	1.9	3.33	2.85	7.27	3.75	1.55	1.87	3.23	2.51
	150	14	-	2.62	4.05	5.1	8.2	3.5	6.4	3.06	2.75	6.59	3.49	1.52	1.89	2.38	2.42
	180	16	11.4	2.51	3.38	5.1	7.3	0.8	2.7	4.03	3.10	10.63	4.05	1.84	2.11	4.29	2.84
	150	16	-	2.60	4.17	5.0	6.9	3.5	5.8	3.02	2.88	5.83	3.71	1.57	1.99	2.13	2.65
III	180	14	8.3	2.97	5.47	5.9	10.9	1.1	2.8	4.69	2.87	10.83	4.36	2.27	1.96	4.73	3.00
	150	14	-	3.22	5.33	5.7	10.4	5.4	10.6	3.36	2.74	8.93	3.88	1.68	1.87	4.04	2.69

Table 1. IISVA TNWS "Mudyug" model test results (From Reference 8).

Table 2. Comparison between HSVA "Thyssen/Waas Mudyug" model and SMP84 hydrostatics.

ICEBREAKER "MUDYUG" HYDROSTATICS

• TNWS Forebody Model 3268-0101

Parameter [†]	HSVA	SMP84
L_{PP} (ft)	257.54	257.54
B(ft)	68.63	68.63
T(ft)	19.68	19.68
A_{WP} (ft ²)	17092.7	16750.1
C_B	0.681	0.676
C_M	0.898	0.899
C_P	0.758	0.752
$T\phi$ (sec)	10.0	10.0
Δ (LT)	6775.8	6722.5

[†]Note: 1 foot= 0.3048 meters.

Table 3. Vertical displacement comparison between HSVA model test and SMP84 numerical predictions.

ICEBREAKER "MUDYUG" WITH TNWS BOW

• Head Seas

$H_{1/3}(m)$	Speed (knots)	$Z_D (m)^{\dagger}$	
		HSVA	SMP84 [‡]
3.10	14	1.01	1.40
5.25	10	2.48	2.46
5.25	11	2.51	2.57
7.40	8	2.97	3.48

[†]Vertical Displacement at the Deck House (Station 5.5).
Significant Single Amplitude.

[‡]Modified version of SMP84 used to allow 20 offsets per station.

Table 4. Pitch motion comparison between HSVA model test and SMP84 numerical predictions.

ICEBREAKER "MUDYUG" WITH TNWS BOW

• Head Seas

H _{1/3} (m)	Speed (knots)	Pitch (deg) [†]	
		HSVA	SMP84‡
3.10	14	2.2	2.3
5.25	10	5.4	4.2
5.25	11	5.1	4.1
7.40	8	5.9	6.0

[†]Significant Single Amplitude.

[‡]Modified version of SMP84 used to allow 20 offsets per station.

Table 5. Comparison between original LDS41 and two proposed ice breaking versions having TNWS type forebodies.

LSD-41 HYDROSTATICS

• SMP84 Calculations

Parameter [†]	ORIGINAL	LSDWAAS	NEWLSD41
L_{WL} (ft)	580.0	580.0	580.0
B(ft)	84.0	83.6	83.6
T(ft)	19.5	17.3	19.5
A_{WP} (ft ²)	37827.9	45534.3	42170.4
C_B	0.583	0.684	0.596
C_M	0.949	0.987	0.946
C_P	0.614	0.693	0.630
KM	43.2	54.4	46.0
Δ (LT)	15839.0	16345.3	16111.7

[†]Note: 1 foot= 0.3048 meters.

Table 6. LSD limiting speeds (20 SLAMS/HR).

• Longcrested Head Seas

Sea State	H _{1/3} (ft)	T _o (sec)	LSD-41 Station-3	NLSDWAAS Station-0
4	6.2	7	> 30 Kts	> 30 Kts
5	10.7	9	> 30 Kts	14 Kts
6	16.4	11	> 30 Kts	6 Kts
7	24.6	13	12 Kts	2 Kts

Note: 1 foot = .3048 meters.

Table 7. Comparison between Original FFG-7 and Proposed Icebreaking Version having a Thyssen-Waas Forebody.

FFG-7 HYDROSTATICS

• SMP84 Calculations

Parameter [†]	ORIGINAL	FFG7WAAS
L_{WL} (ft)	408.0	408.0
B(ft)	44.8	44.4
T(ft)	14.4	14.4
A_{WP} (ft ²)	13385.5	14166.5
C_B	0.448	0.450
C_M	0.749	0.742
C_P	0.599	0.607
KM	22.75	24.37
Δ (LT)	3373.2	3359.2

[†]Note: 1 foot= 0.3048 meters.

Table 8. FFG Limiting Speeds (20 SLAMS/HR).

• Longcrested Head Seas

Sea State	H _{1/3} (ft)	T _o (sec)	FFG-7 Station-3	FFG7WAAS Station-0
4	6.2	7	> 30 Kts	12 Kts
5	10.7	9	> 30 Kts	2 Kts
6	16.4	11	15 Kts	< 0 Kt
7	24.6	13	9 Kts	< 0 Kt

Note: 1 foot = .3048 meters.

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APPENDIX A
MUDYUG

MUDYUG - HEAVE DISPLACEMENT

HEAD SEAS - LONGCRESTED - 11 SEC

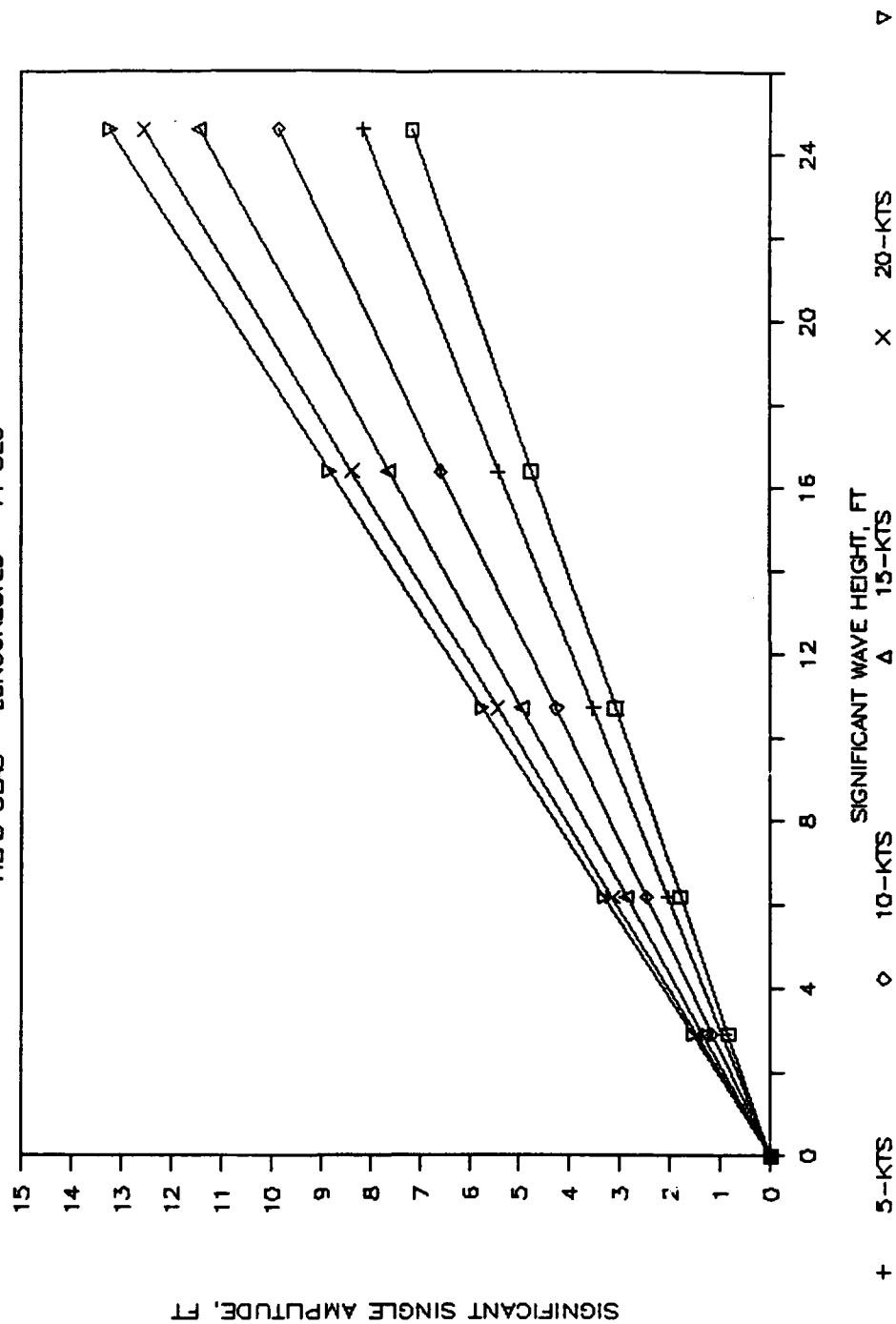


Figure A-1 - MUDYUG Heave Displacement.

MUDYUG - PITCH ANGLE

HEAD SEAS - LONGCRESTED - 11 SEC

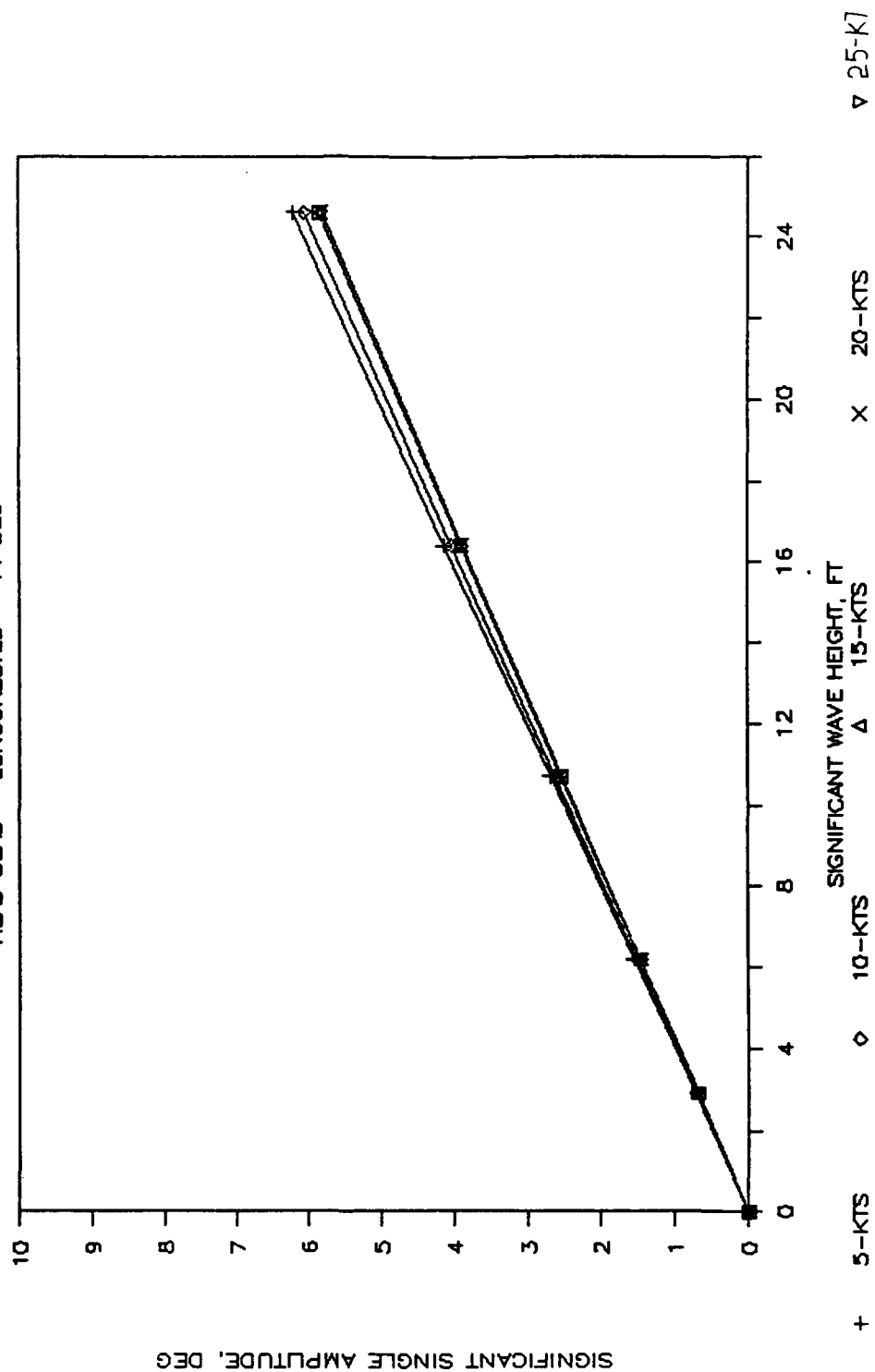


Figure A-2 - MUDYUG Pitch Angle.

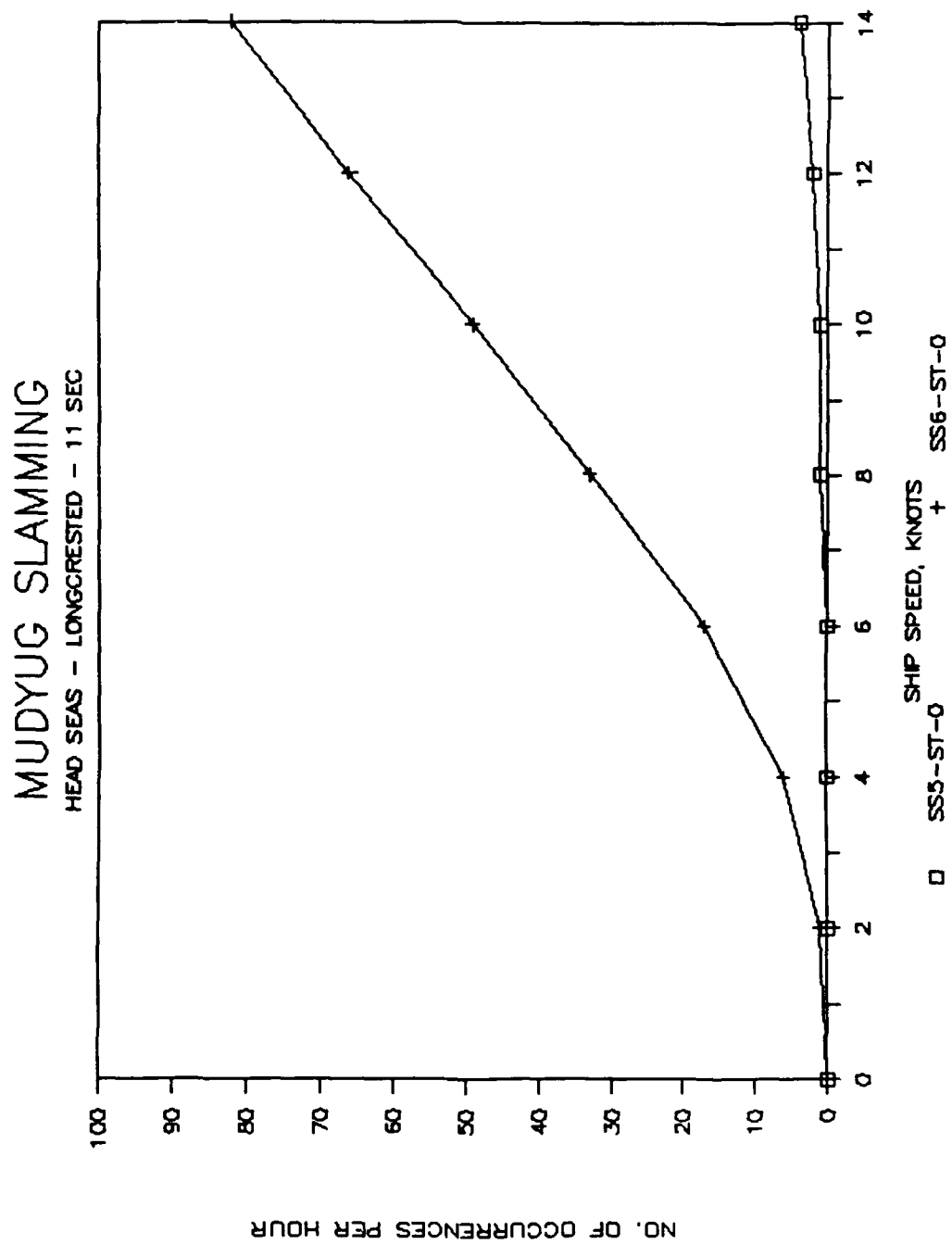


Figure A-3 - MUDYUG Slamming.

APPENDIX B
LSD41

LSD41 -- HEAVE DISPLACEMENT

HEAD SEAS - LONGCRESTED - 11 SEC

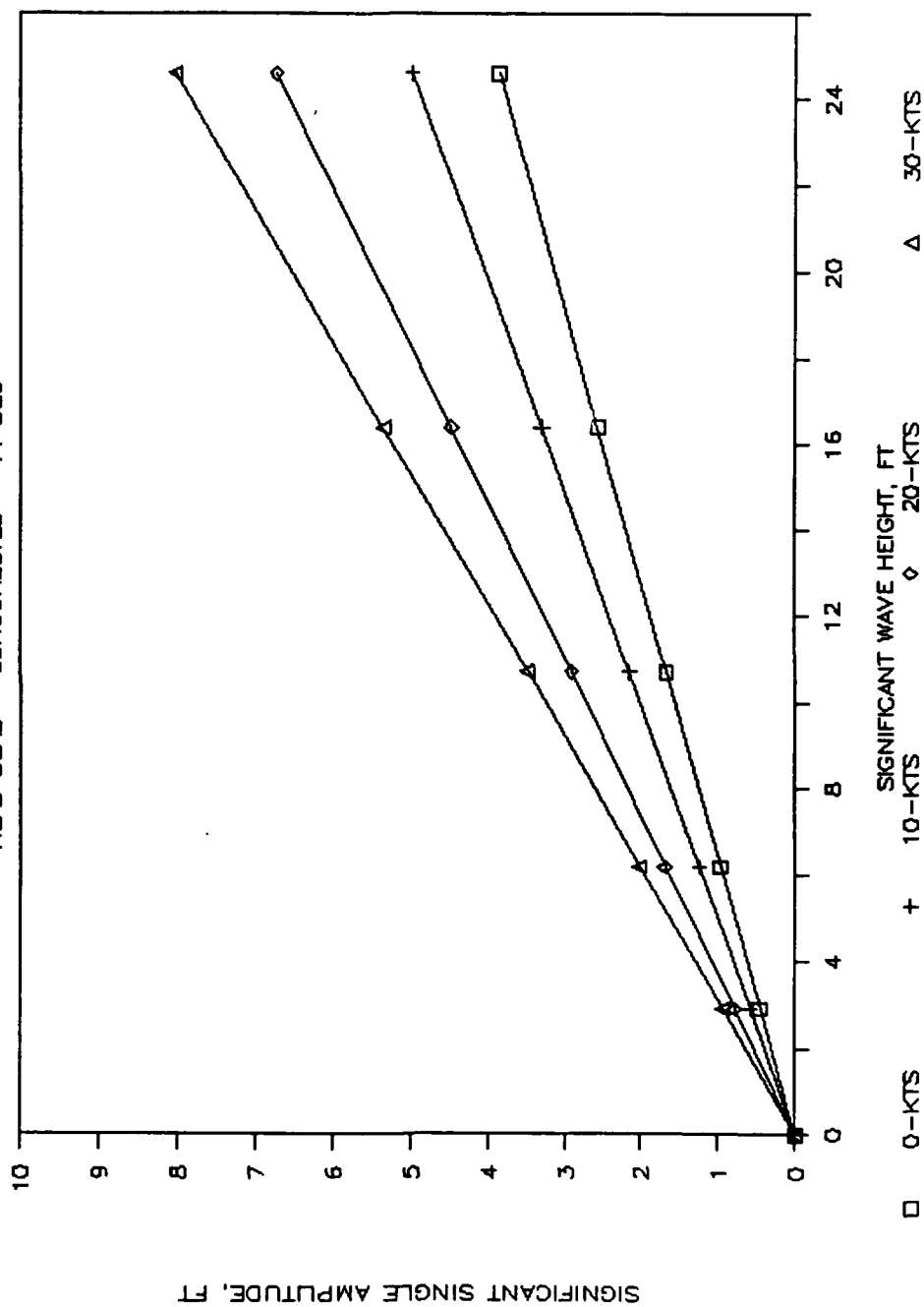


Figure B-1 - LSD41 Heave Displacement.

LSD41 - PITCH ANGLE

HEAD SEAS - LONGCRESTED - 11 SEC

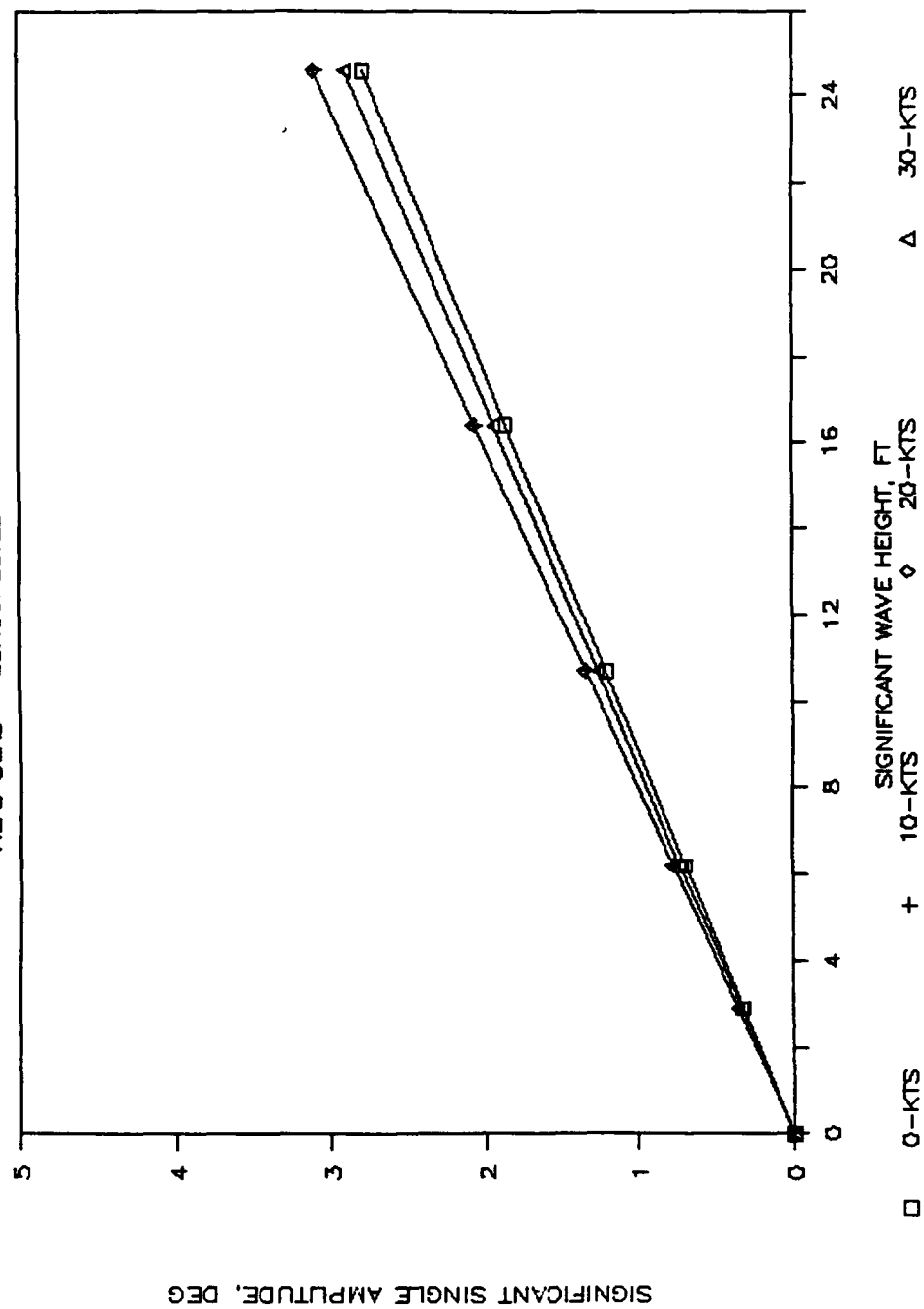


Figure B-2 - LSD41 Pitch Angle.

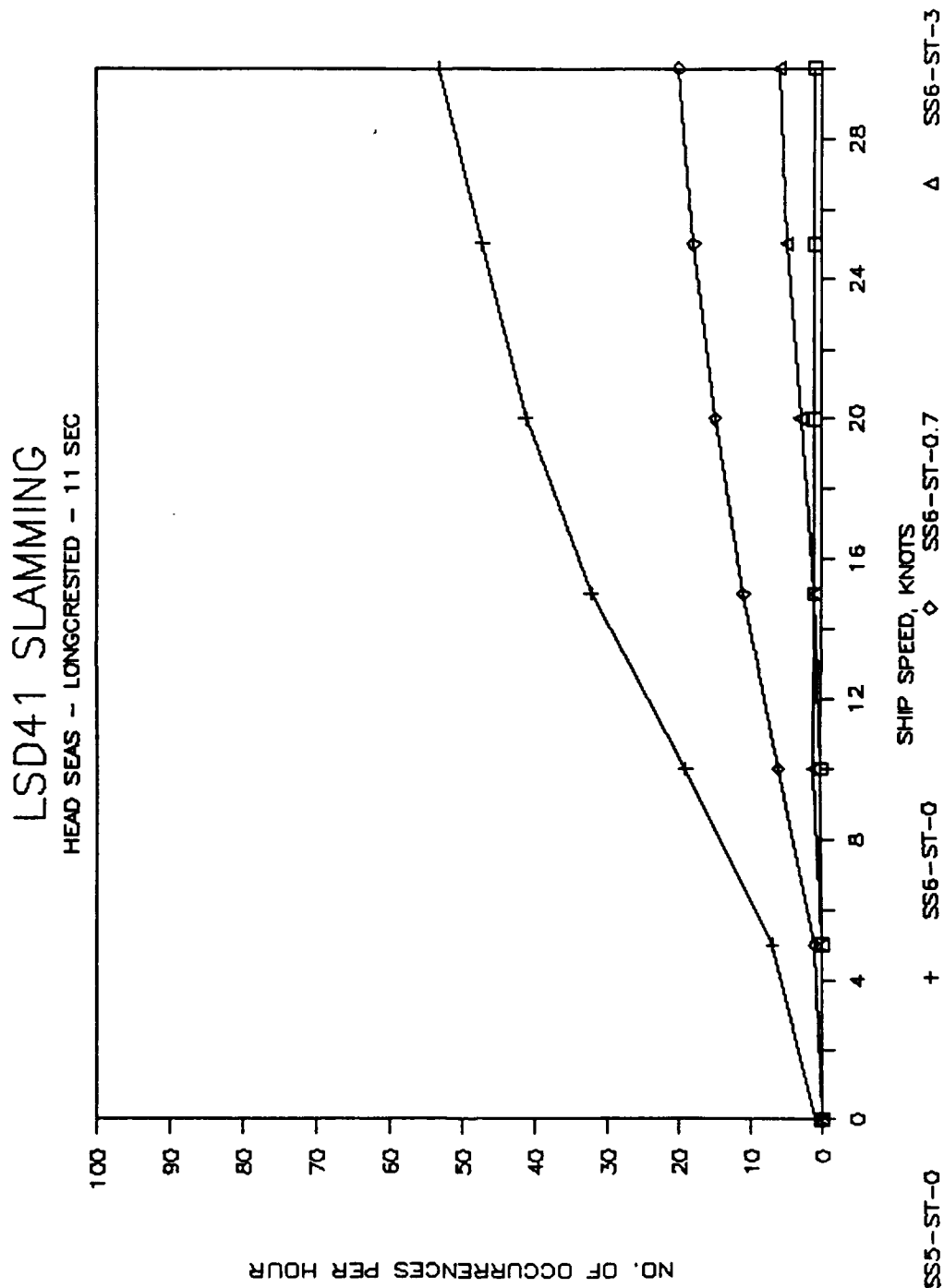


Figure B-3 - LSD41 Slamming.

LSD41WAAS - HEAVE DISPLACEMENT

HEAD SEAS - LONGCRESTED - 11 SEC

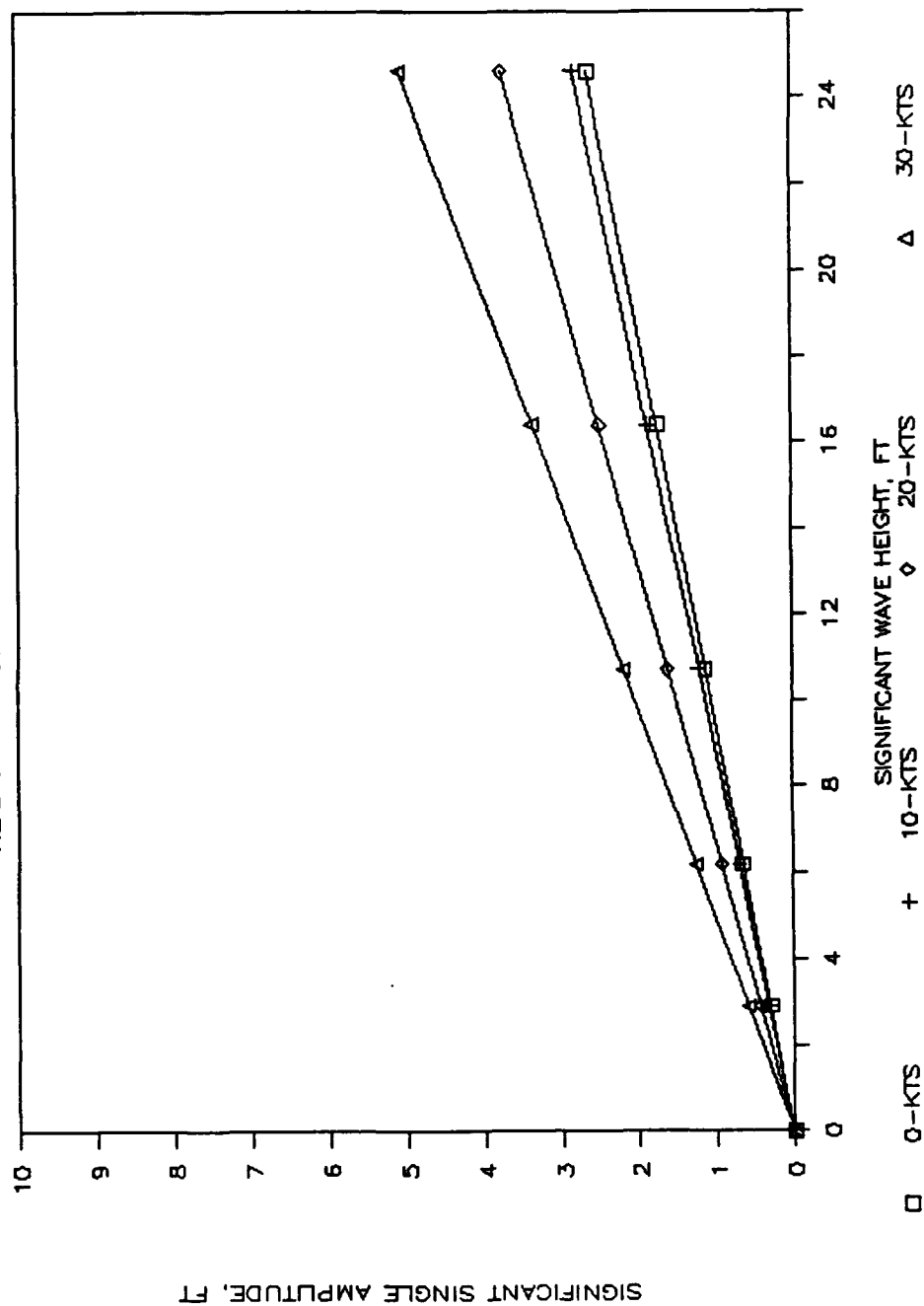


Figure B-4 - LSD41WAAS Heave Displacement.

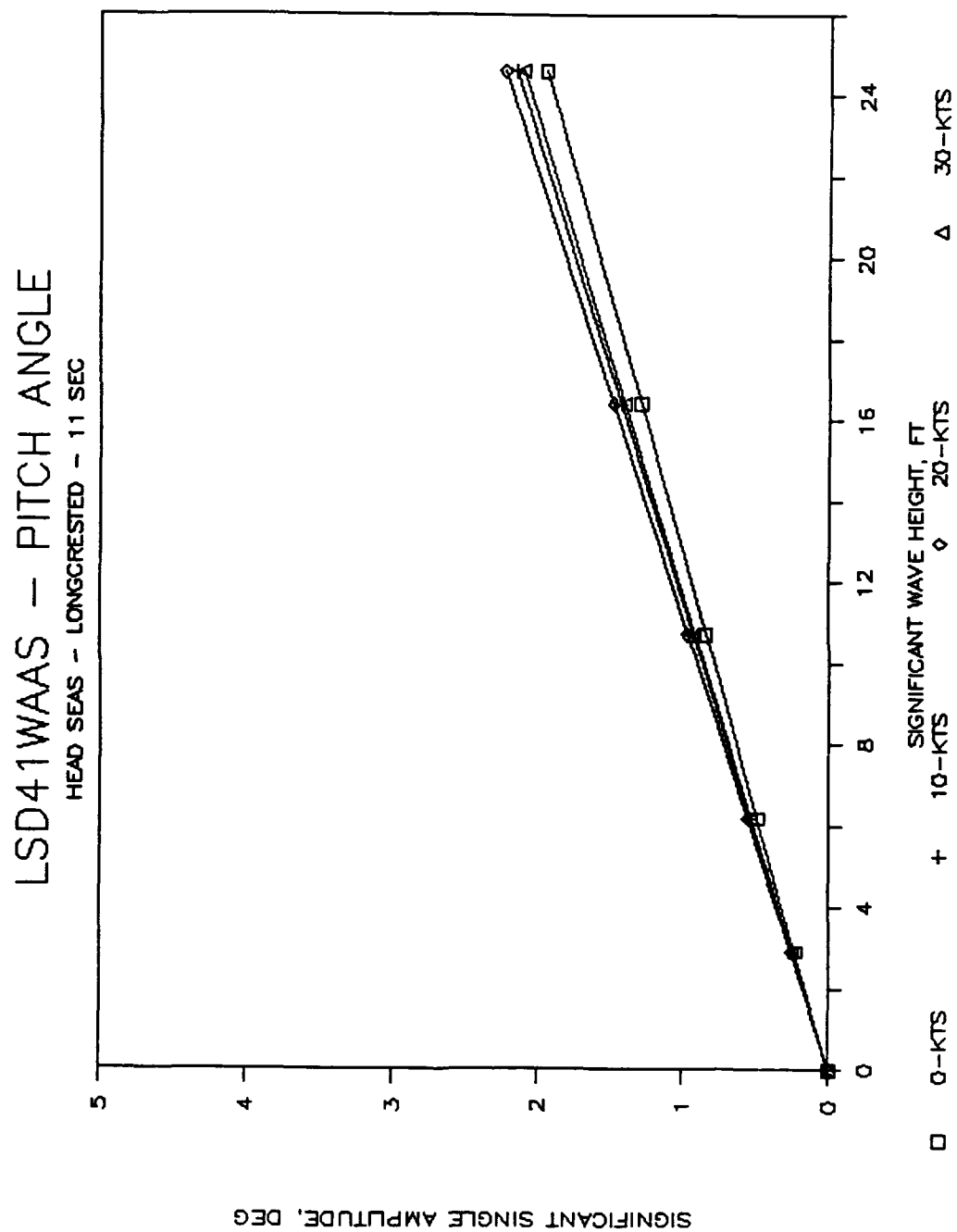


Figure B-5 - LSD41WAAS Pitch Angle.

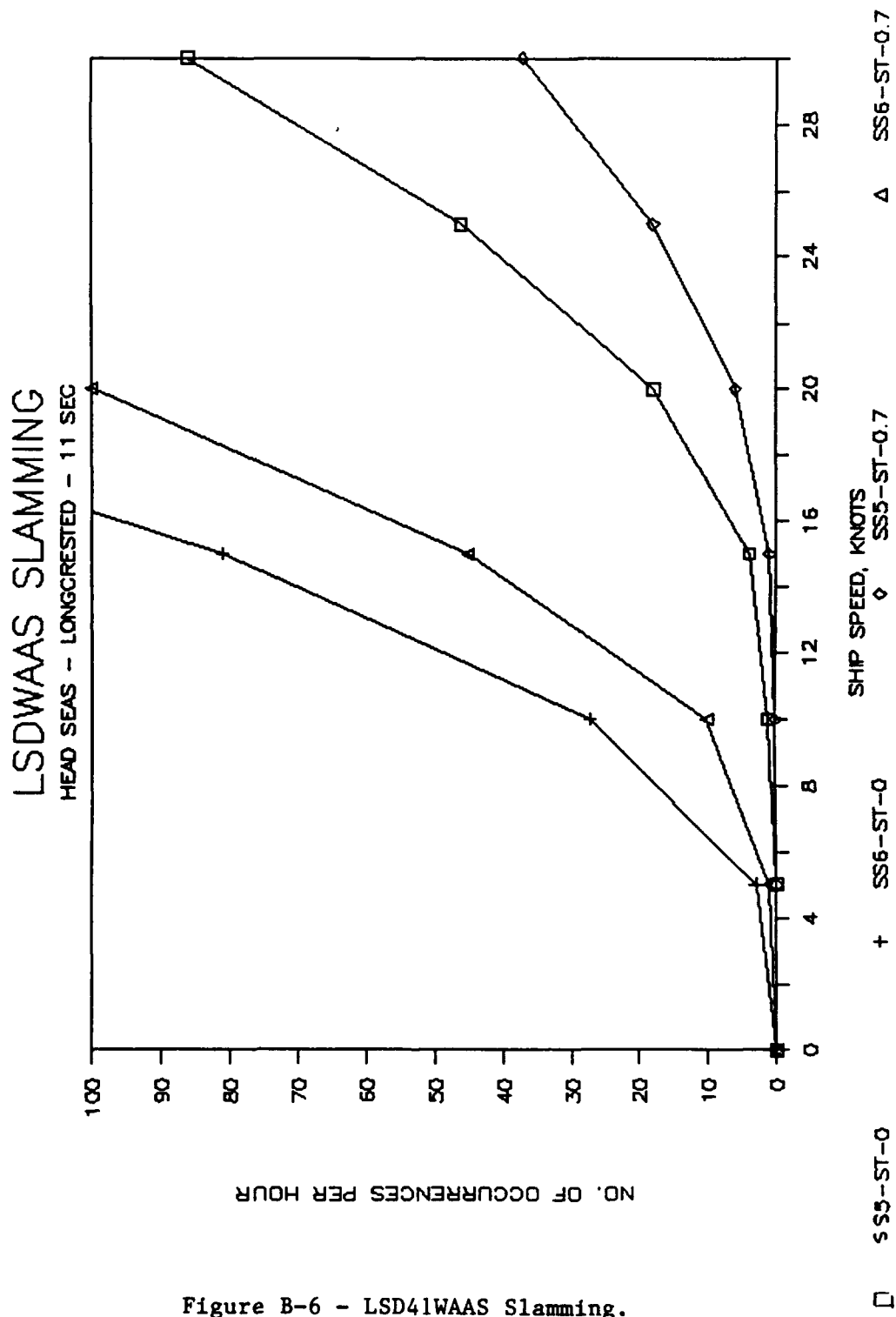


Figure B-6 - LSD41WAAS Slamming.

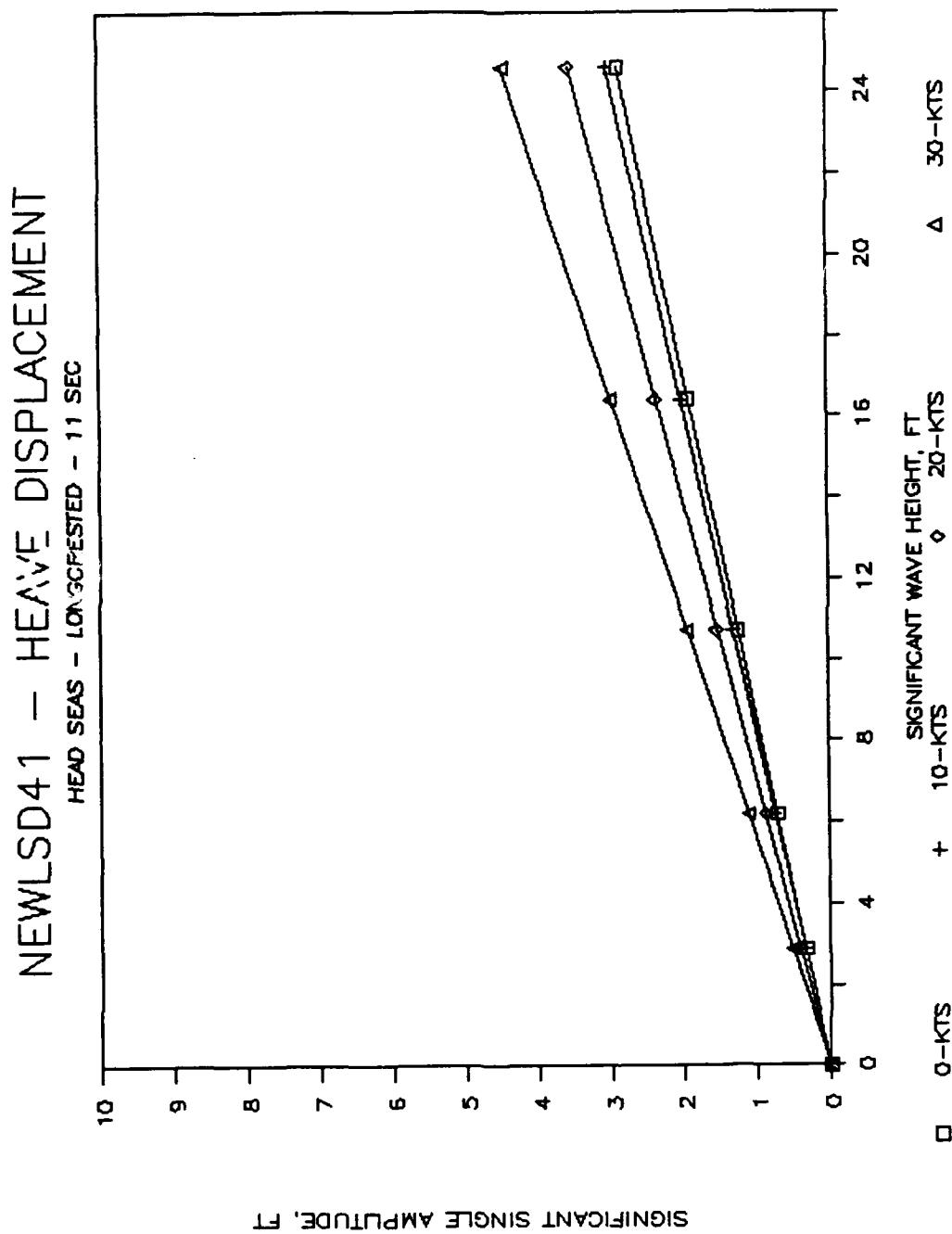


Figure B-7 - NEWLSD41 Heave Displacement.

NEWLSD41 - PITCH ANGLE

HEAD SEAS - LONGCRESTED - 11 SEC

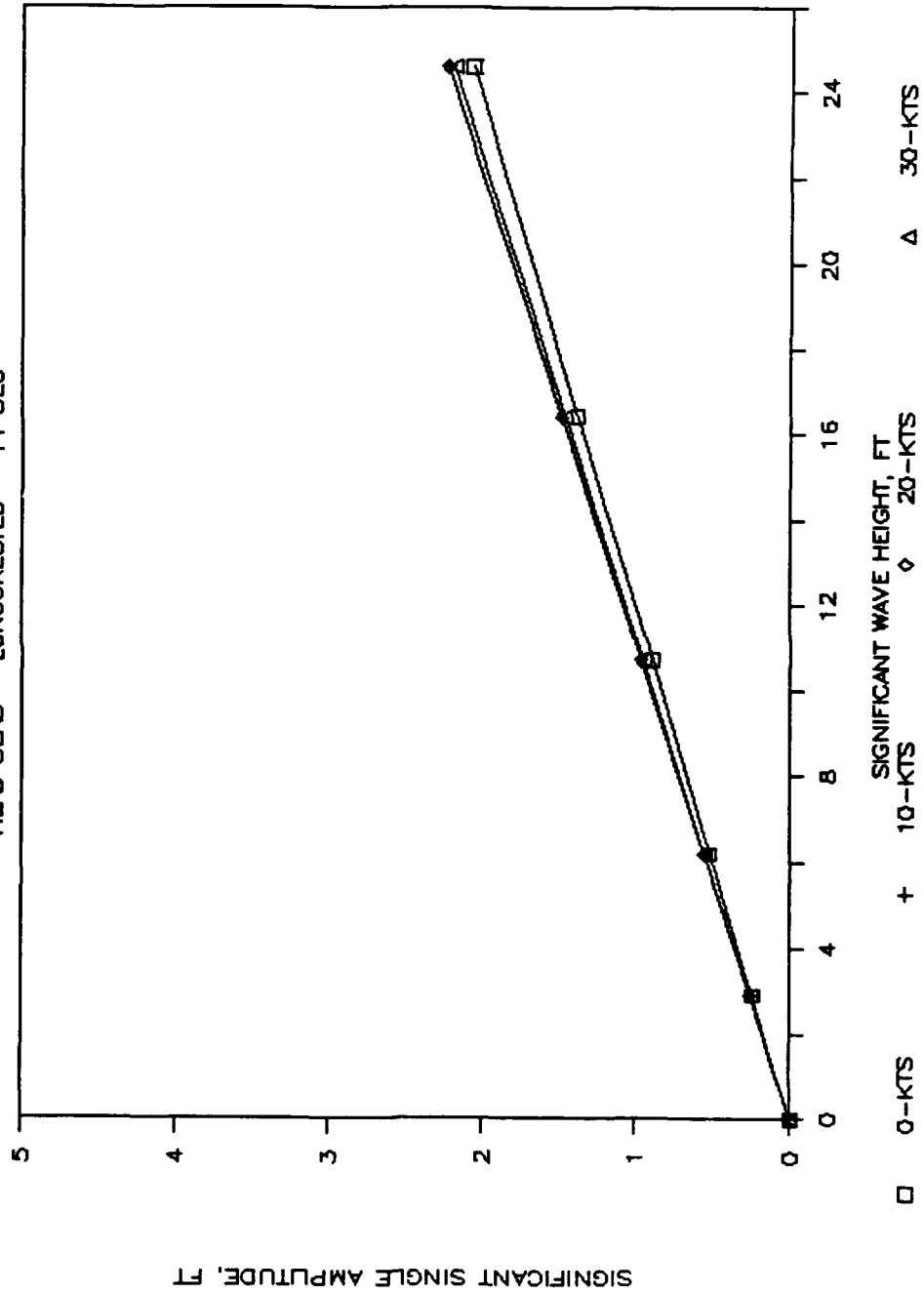


Figure B-8 - NEWLSD41 Pitch Angle.

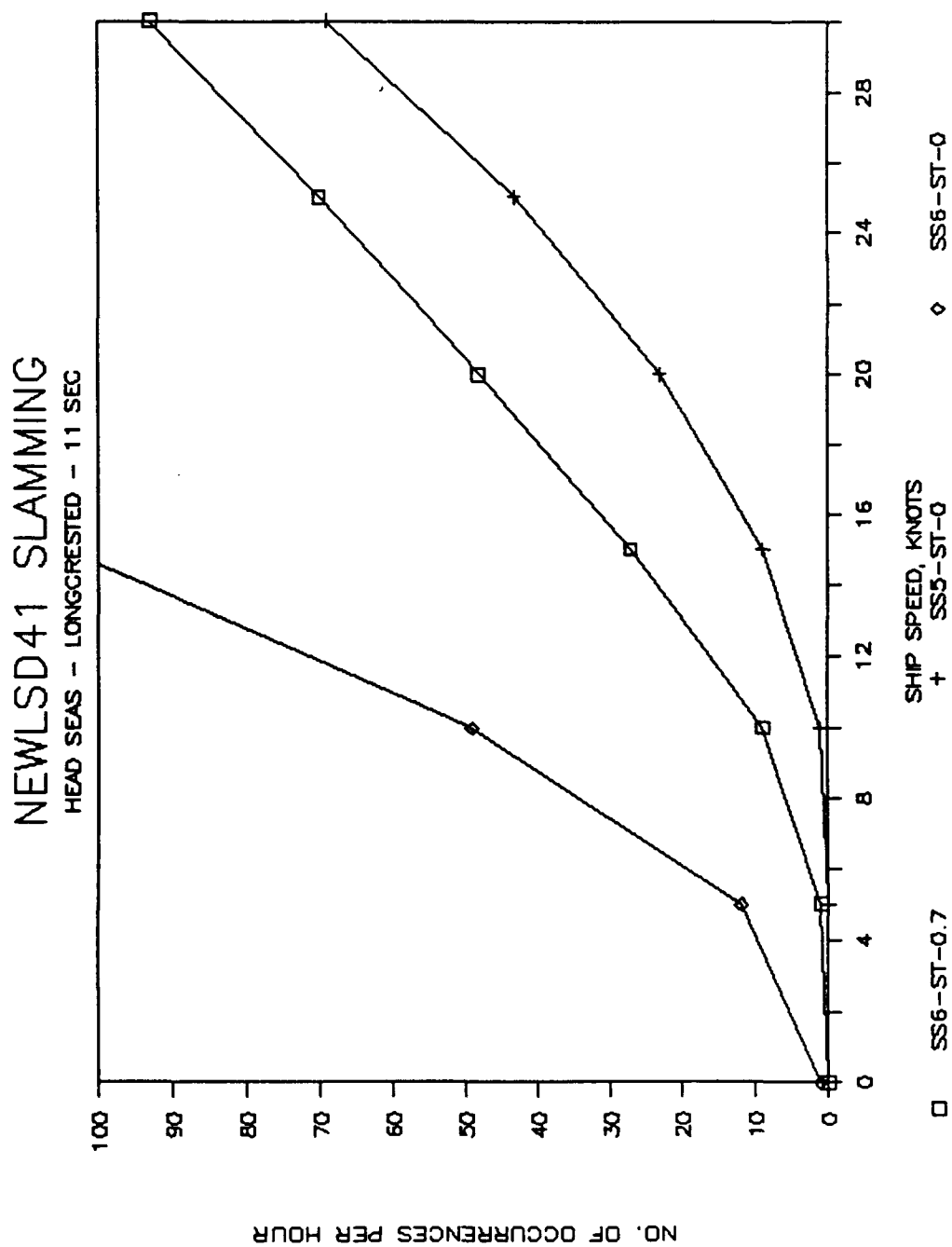


Figure B-9 - NEWLSD41 Slamming.

APPENDIX C
FFG7

FFG7 - HEAVE DISPLACEMENT

HEAD SEAS - LONGCRESTED - 11 SEC

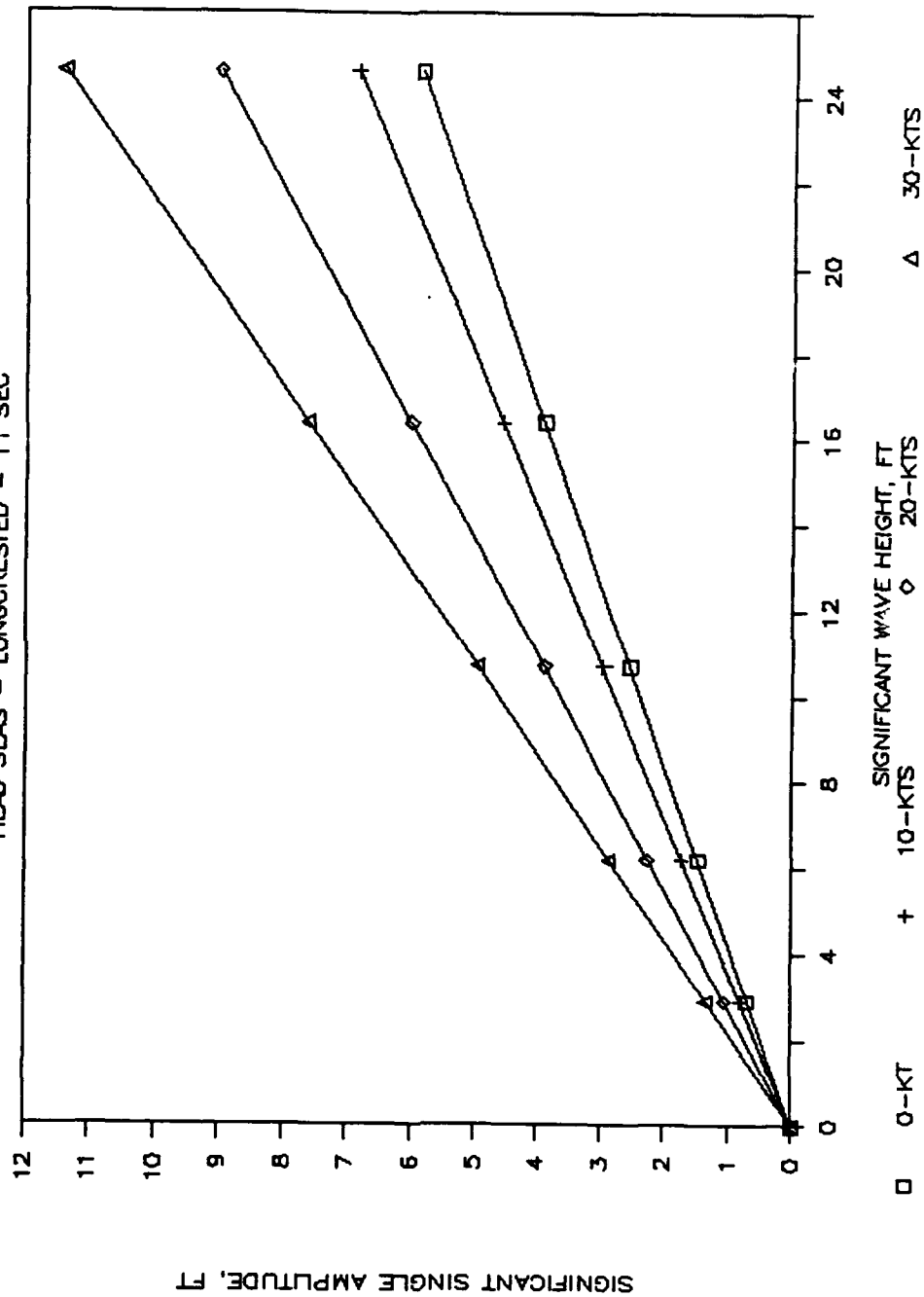


Figure C-1 - FFG7 Heave Displacement.

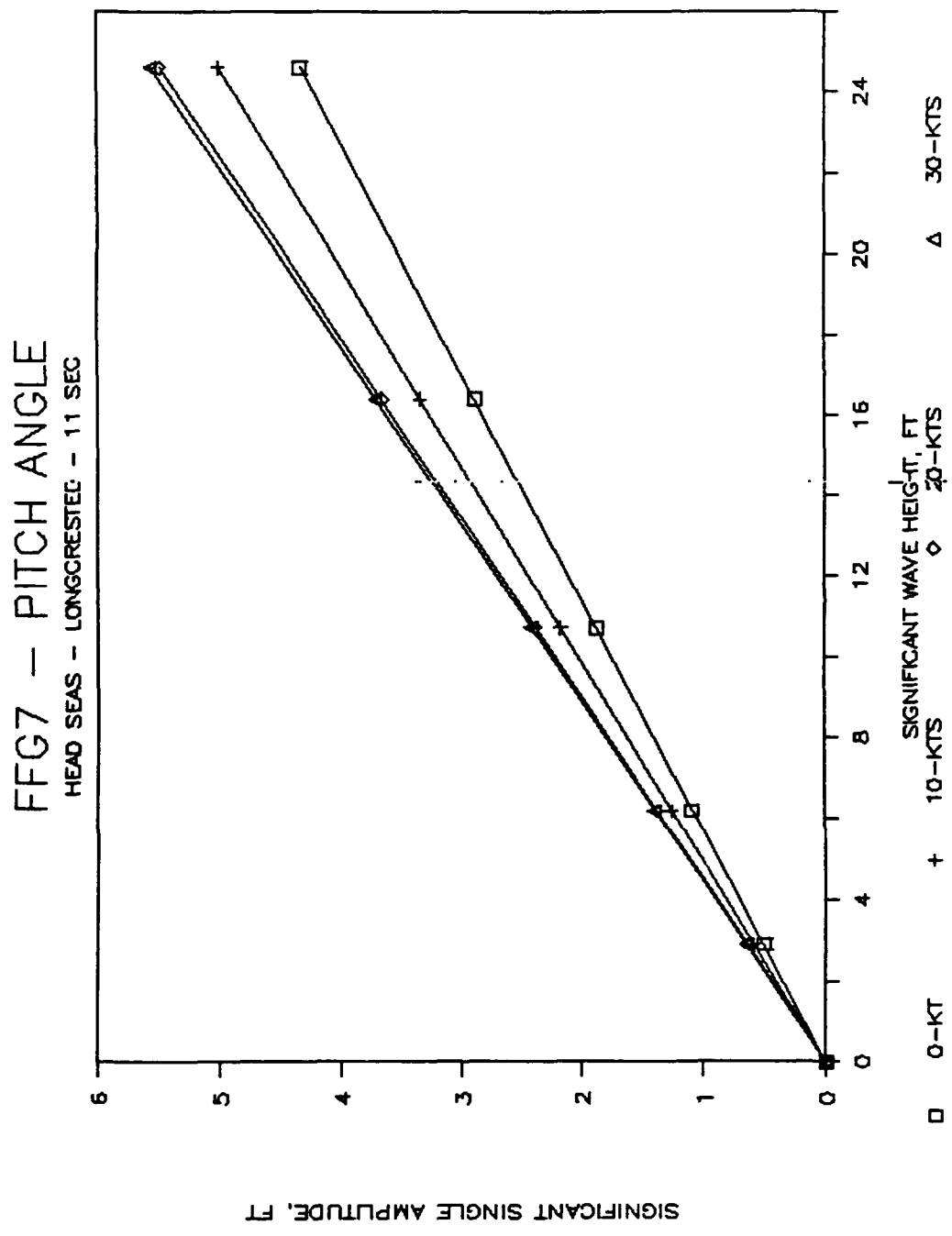


Figure C-2 - FFG7 Pitch Angle.

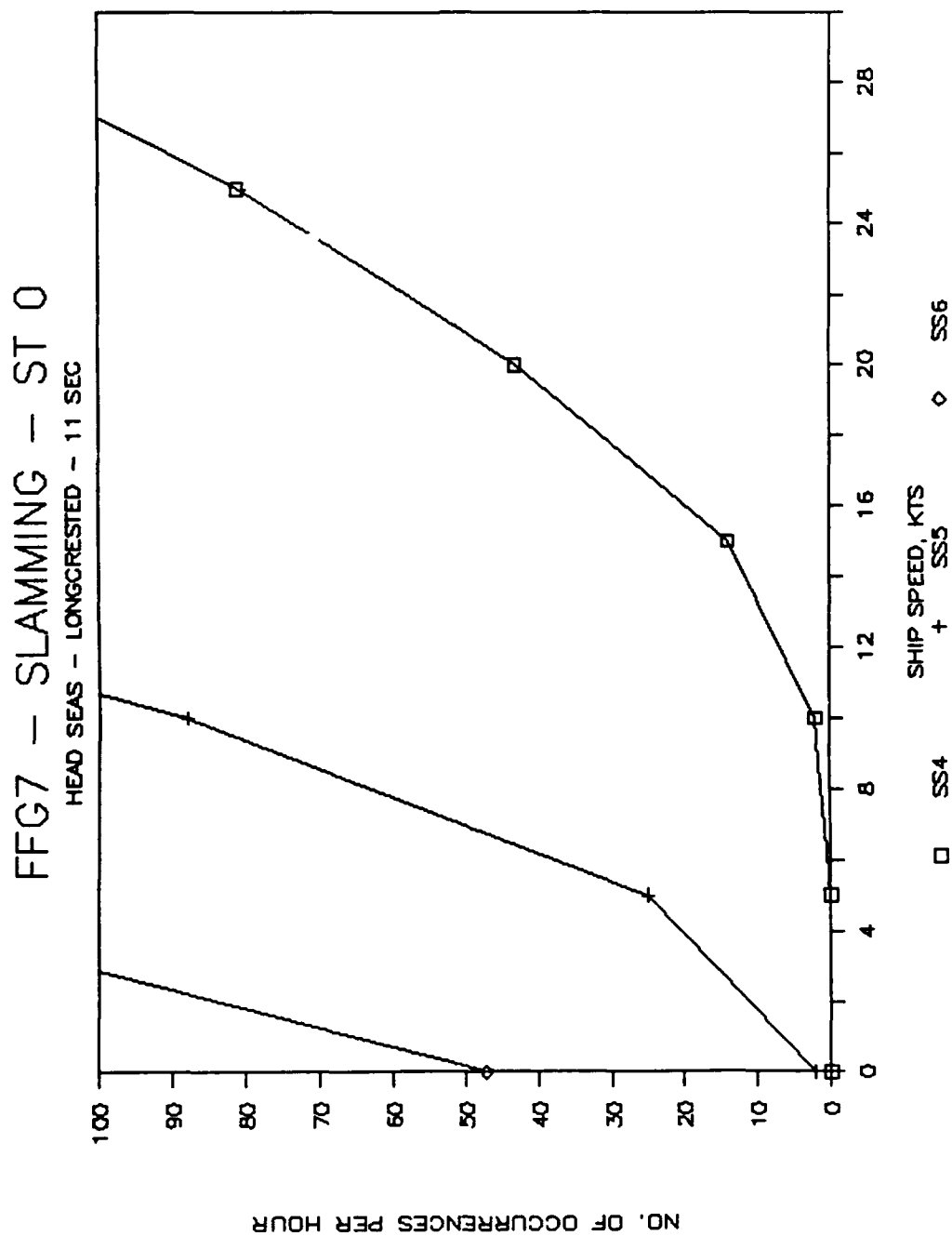


Figure C-3 - FFG7 Slamming at Station 0.

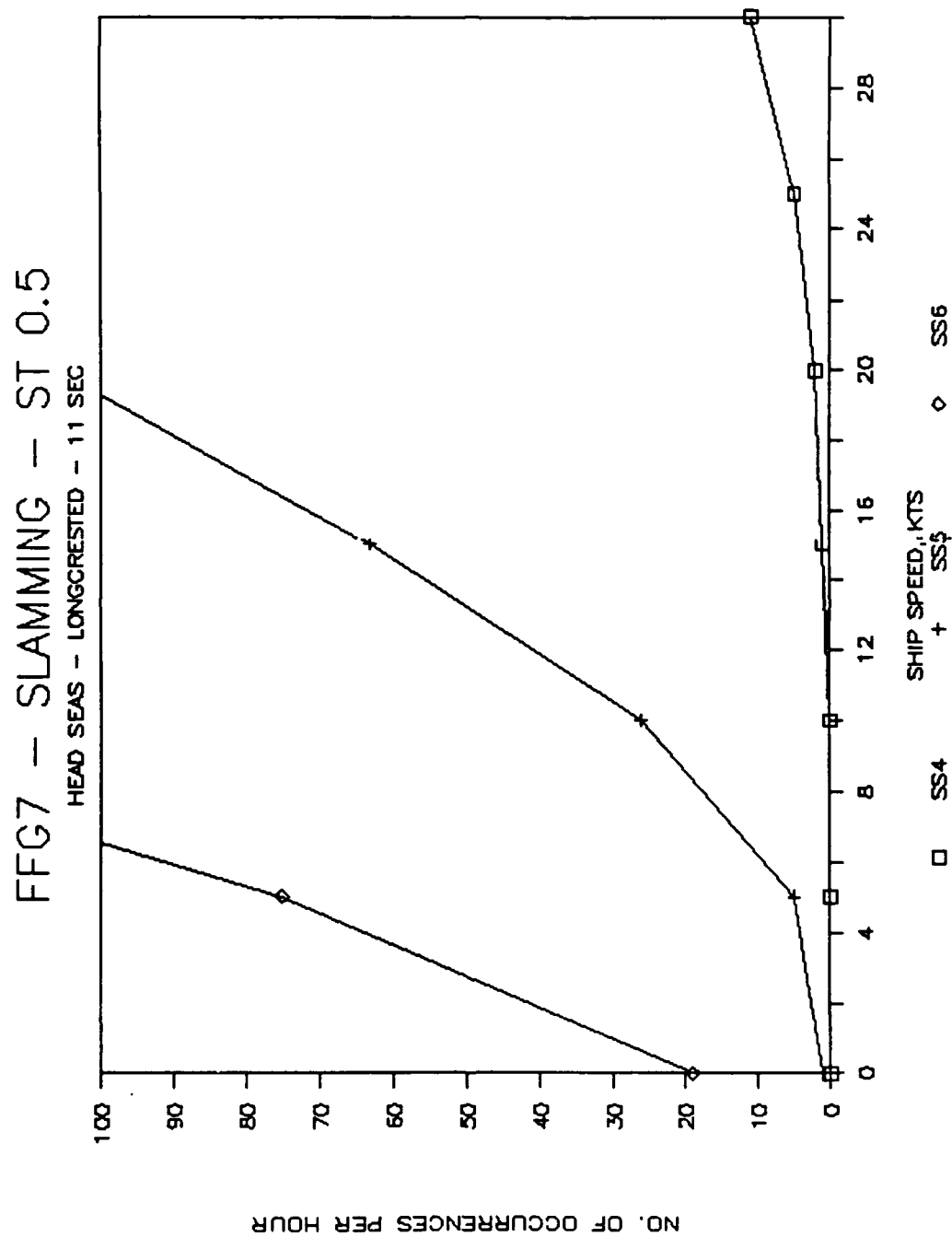


Figure C-4 - FFG7 Slamming at Station 0.5.

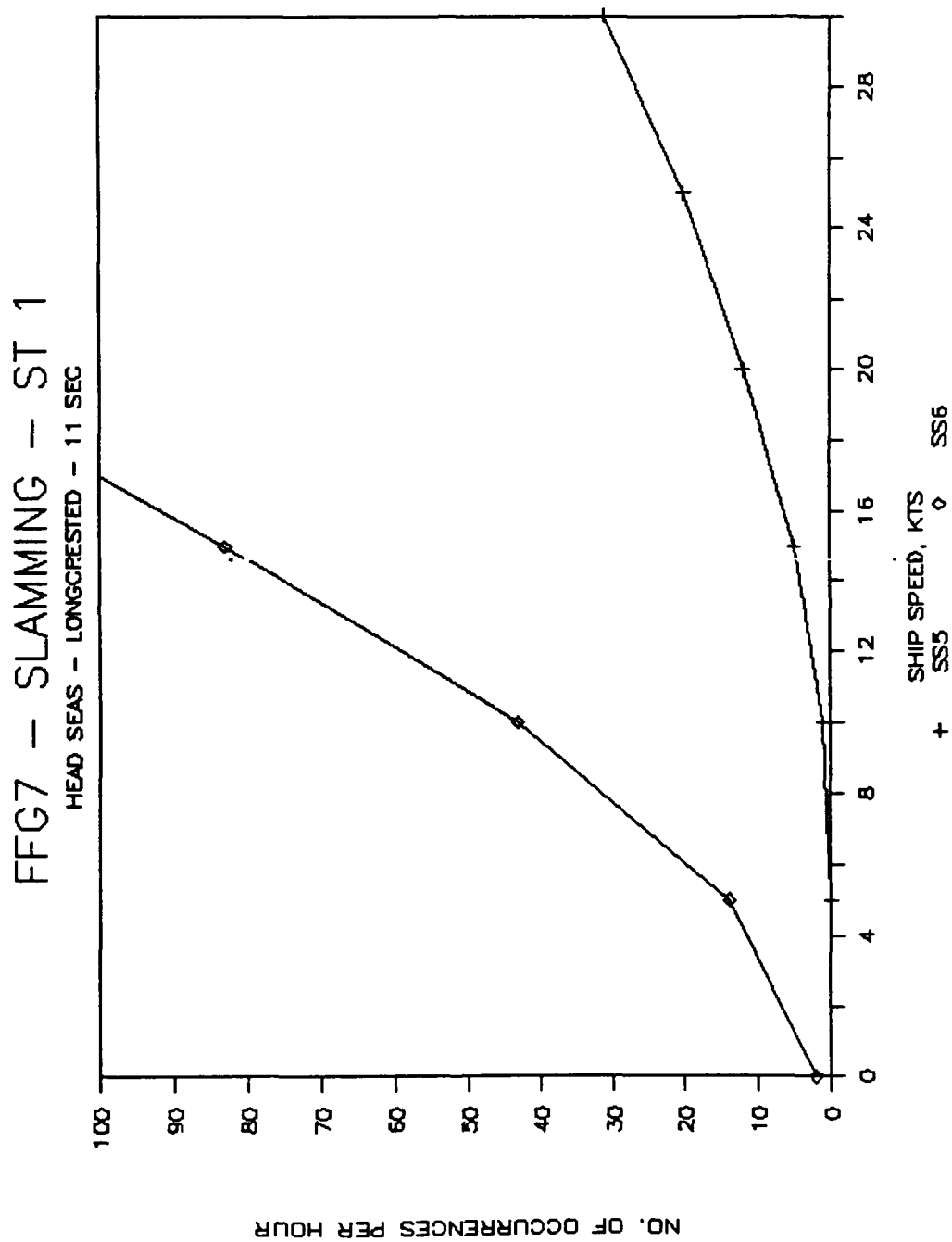


Figure C-5 - FFG7 Slamming at Station 1.

FFG7 - SLAMMING - ST 3

HEAD SEAS - LONGCRESTED - 11 SEC

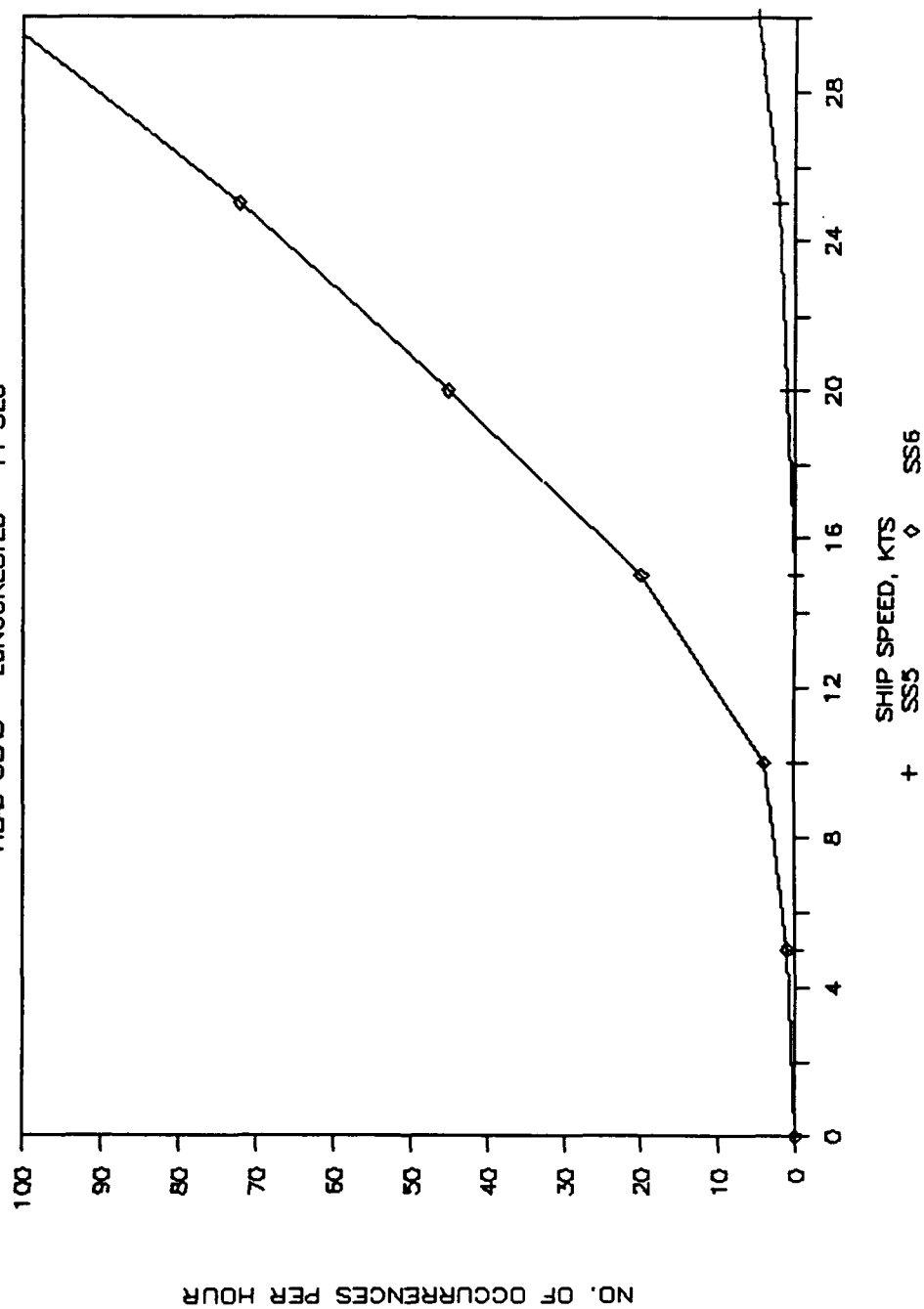


Figure C-6 - FFG7 Slamming at Station 3.

FFGWAAS - HEAVE DISPLACEMENT

HEAD SEAS - LONGCRESTED - 11 SEC

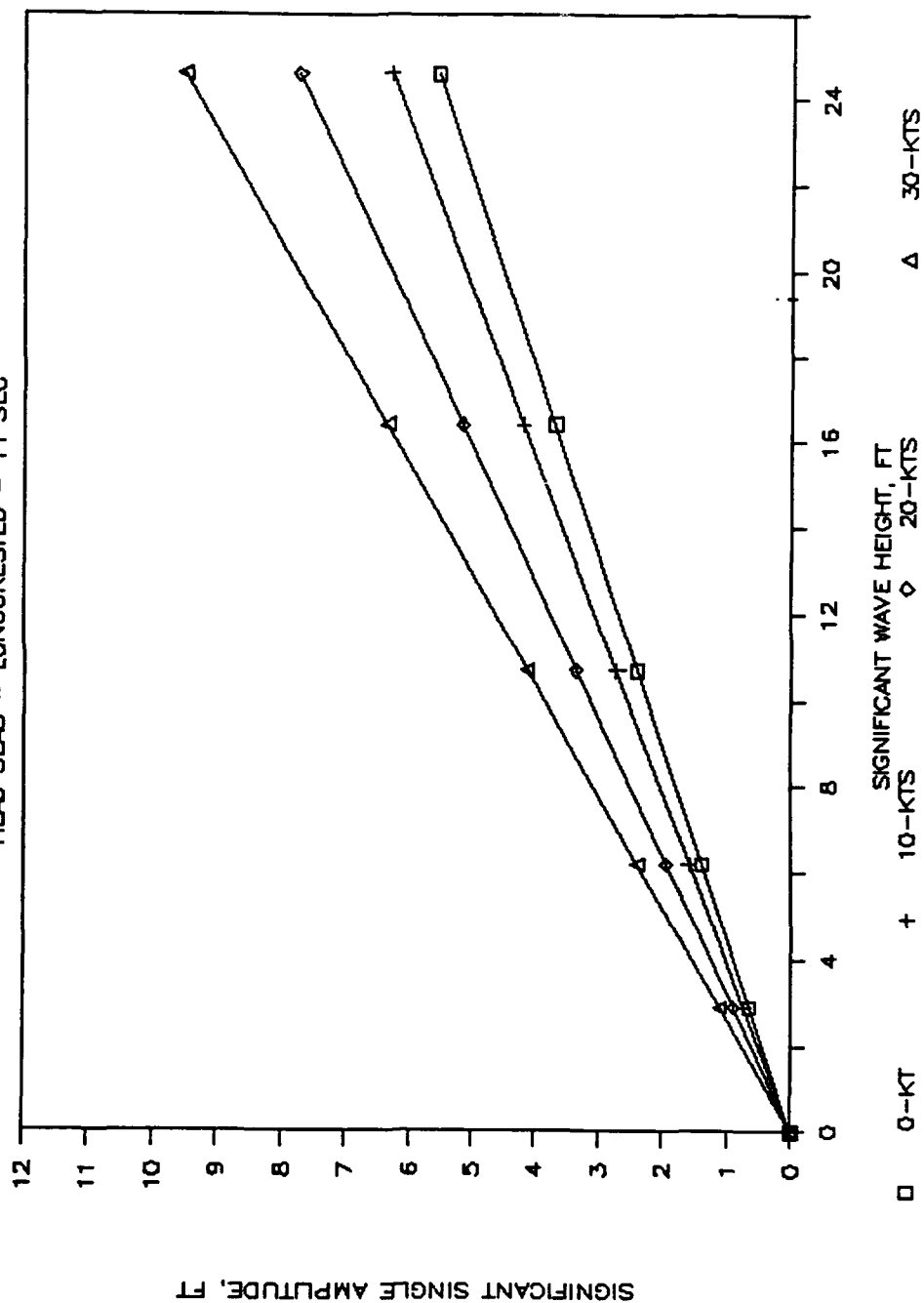


Figure C-7 - FFG7WAAS Heave Displacement.

FFGWAAS - PITCH ANGLE

HEAD SEAS - LONGCRESTED - 11 SEC

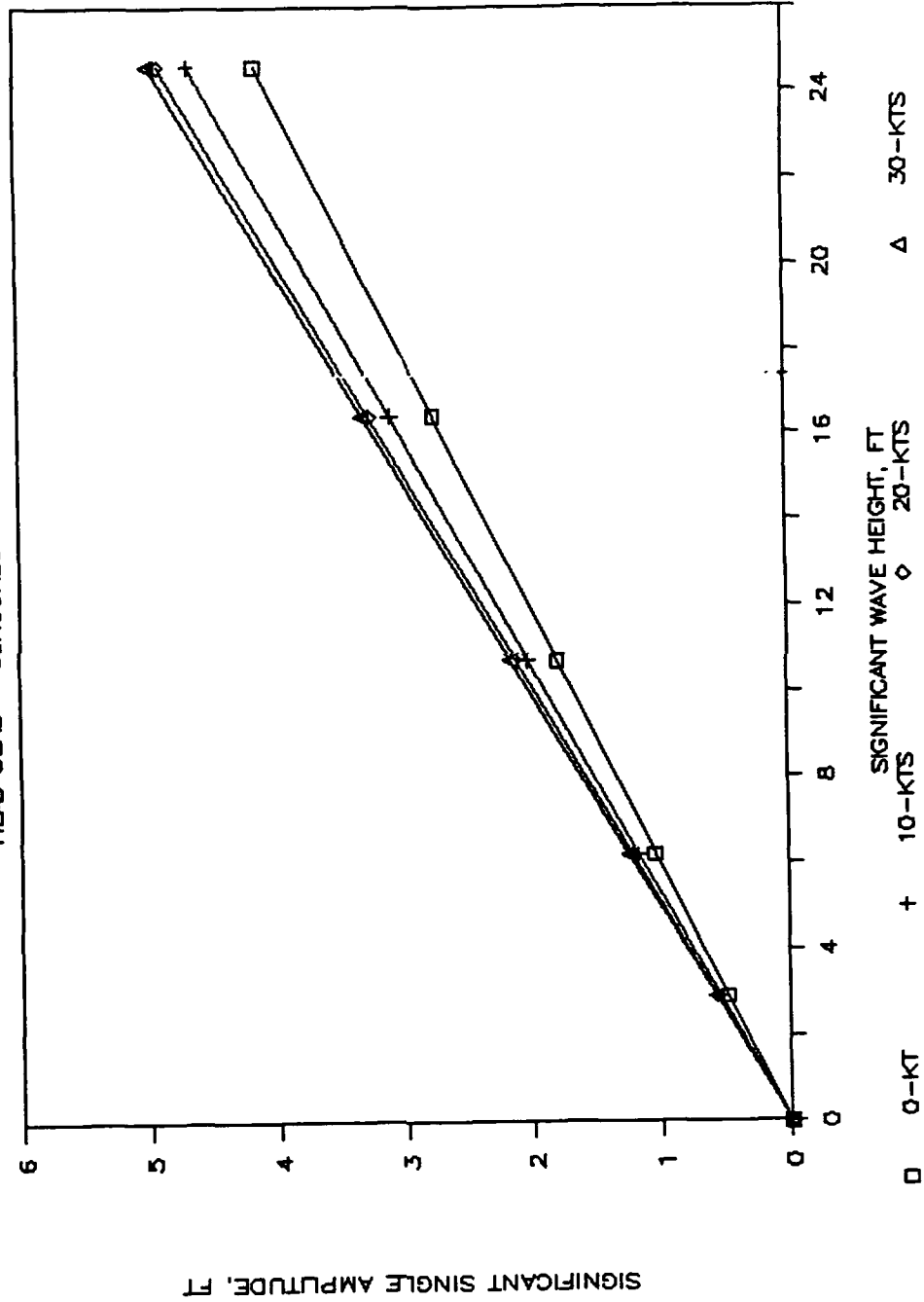


Figure C-8 - FFG7WAAS Pitch Angle.

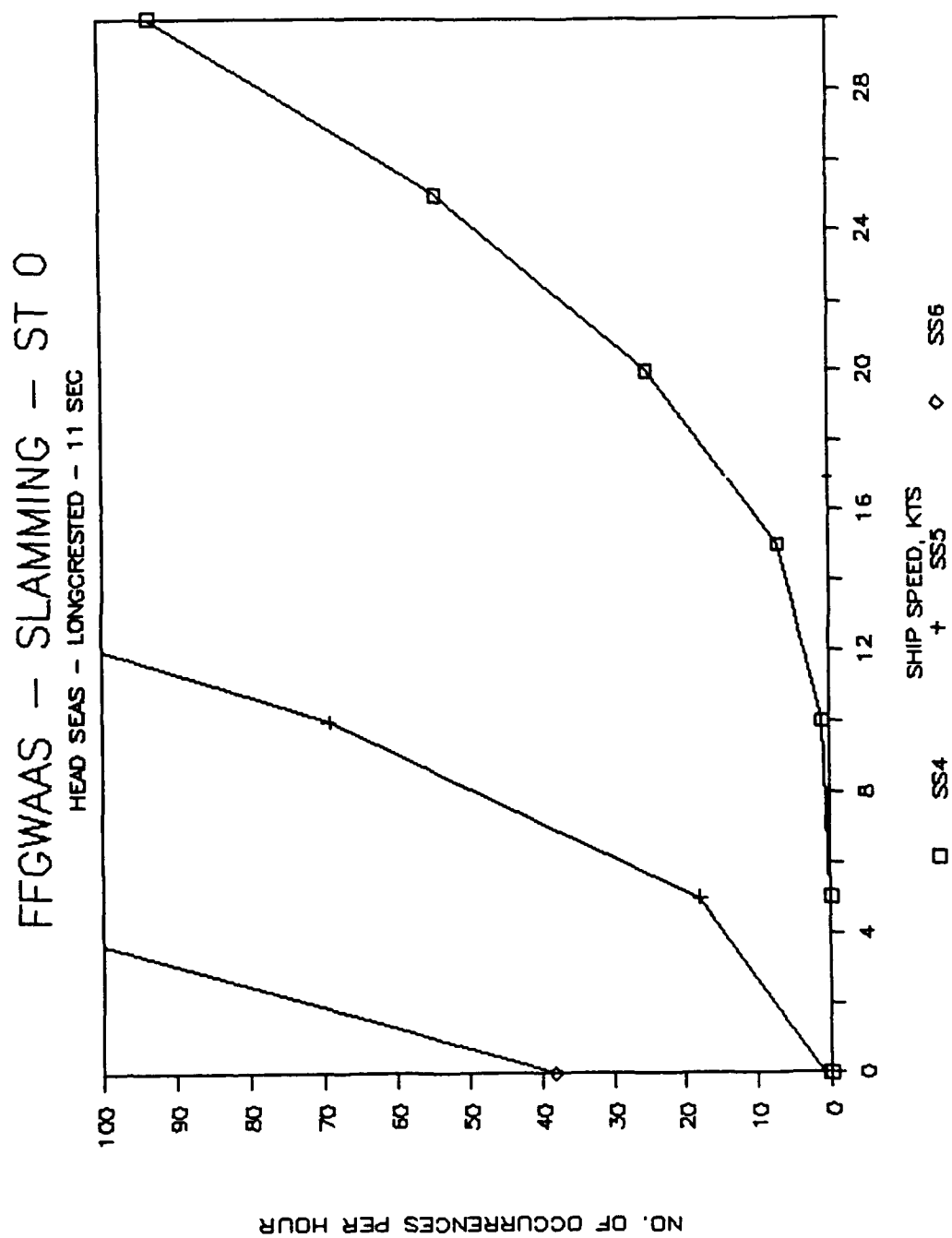


Figure C-9 - FFG7WAAS Slamming at Station 0.

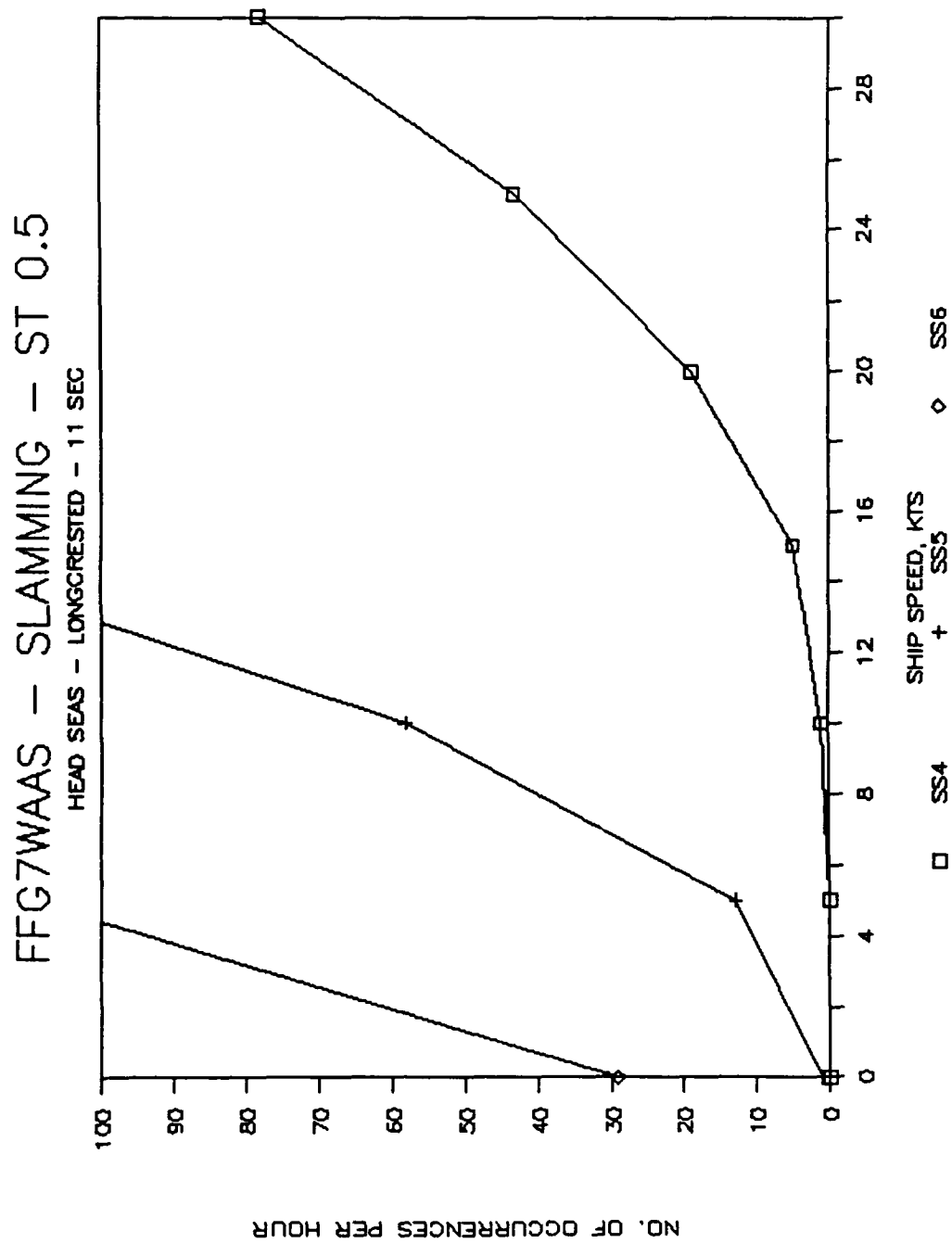


Figure C-10 - FFG7WAAS Slamming at Station 0.5.

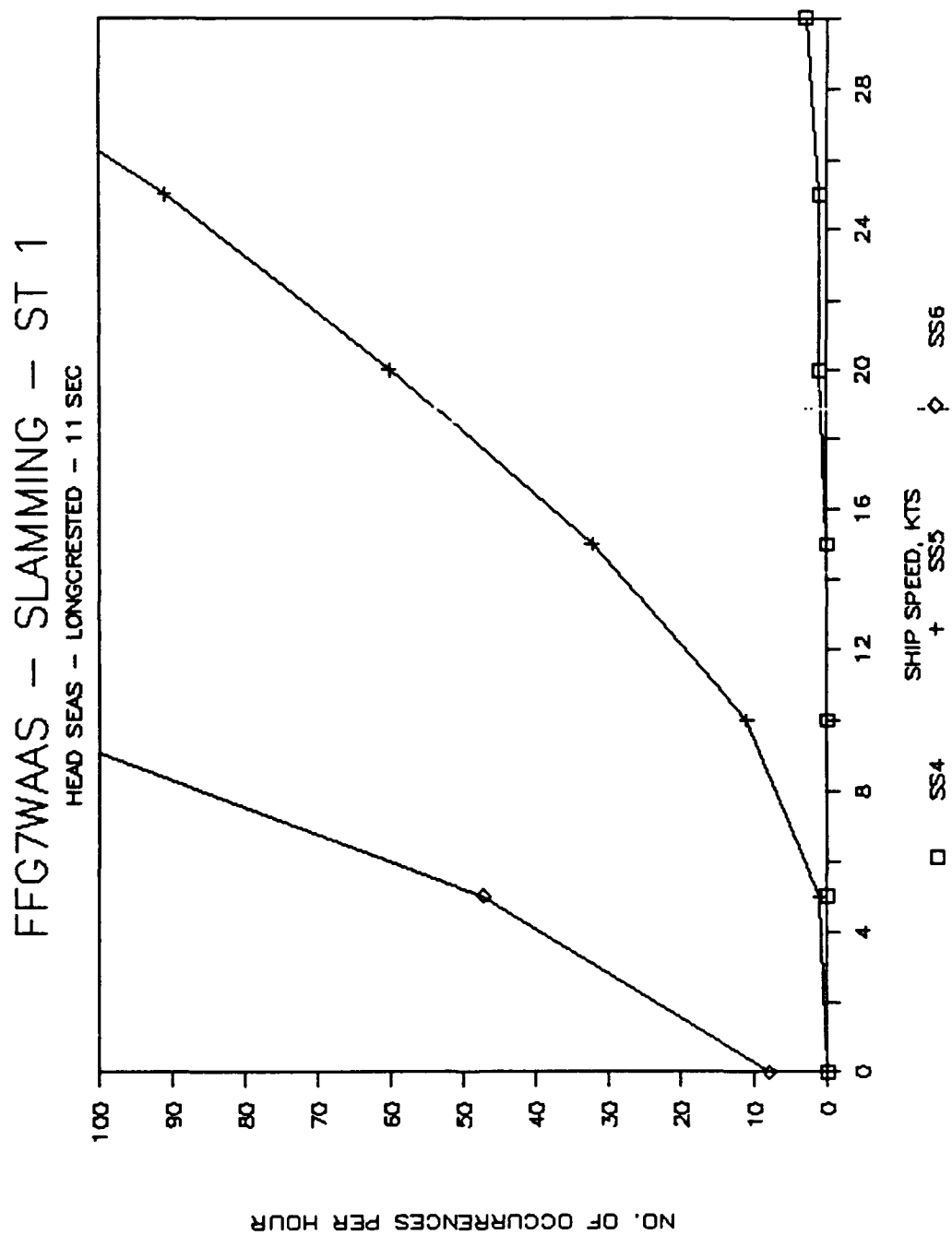


Figure C-11 - FFG7WAAS Slamming at Station 1.

FFG7WAAS - SLAMMING - ST 3

HEAD SEAS - LONGCRESTED - 11 SEC

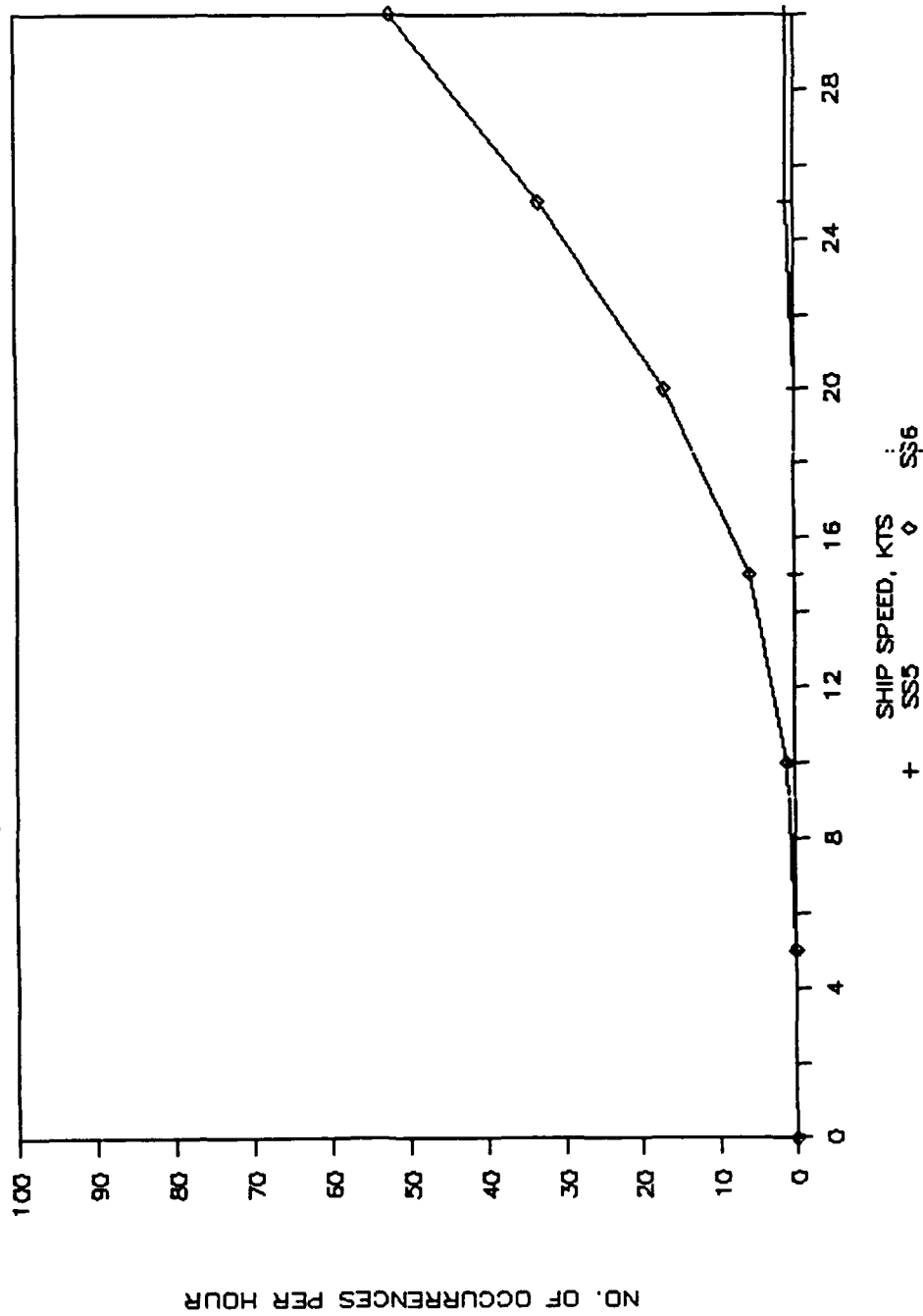


Figure C-12 - FFG7WAAS Slamming at Station 3.